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LEAK TESTS OF WELLS FOR NEW SOLUTION MINED CAVERNS AT THE WEST HACKBERRY DOE-SPR STORAGE SITES

Kennith L. Goin
SPR Geotechnical Division 4543
Sandia National Laboratories
Albuquerque, NM 87185

Abstract

Results are presented for leak tests of 15 wells. Leak rates of the wells meet the DOE leak rate criterion of no more than 100 barrels per year per cavern, or approach this criterion near enough to be acceptable.

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Introduction

The Strategic Petroleum Reserve is a national program involving the underground storage of crude oil in salt dome cavities located in the Texas-Louisiana gulf coast area. To achieve the required storage capacity, construction of a number of new underground caverns is currently being implemented at DOE sites at the Bryan Mound salt dome in Texas and at the West Hackberry and Bayou Choctaw salt domes in Louisiana. Such caverns are cavities in the salt domes leached away by the circulaton of raw water through wells. Groups of wells for new caverns have been completed at the Bryan Mound and West Hackberry sites and a single well has been completed at the Bayou Choctaw site. Leaching of new caverns is well underway at the Bryan Mound site and has been started at the West Hackberry site.

DOE has established a criterion of 100 barrels per year maximum leak rate from each cavern. Prior to beginning use of wells for new cavern leaching, it is necessary to determine leak rates of the wells, as leakage from the completed cavern is expected to equal or exceed that from the well used for leaching. Such well tests can be expected to indicate unacceptable leak rates for completed caverns, but conversely, cannot insure that the completed cavern leak rate will be acceptable.

Pressure tests were run on 15 of the recently completed 16 wells at the West Hackberry site to determine well leakage rates. The tests were made by Williams-Fenix and Scisson using subcontractors Rayorback Oil Tools, Inc. for pressurizing the wells and Lynes, Inc. for providing pressure measuring instrumentation. The tests were observed by representatives of Sandia Labs. Test results are included herein.

Description of Wells

A schematic of typical well construction is shown in Figure 1, along with details for the individual wells from Reference 1 to 16. A surface casing to a depth near top of caprock is cemented to the surface. A smaller 26-inch diameter intermediate casing into the top of the salt is cemented to the surface. A smaller (20-inch) diameter production casing generally about 400 feet into the salt is cemented to the surface. The bottom of the production casing is somewhat above the top of the cavern to be developed. Two concentric casings hang inside the production casing: the larger diameter "first" string to a depth somewhat below the bottom of the production casing and below the planned cavern roof; and the smaller diameter "second" string to a depth near the bottom of the well. Leaching of salt from the uncased walls of the borehole is accomplished by flowing water to the bottom of the well through the second hanging string and removing brine through the annulus between the two hanging strings until a sump volume adequate to accommodate the insolubles in the salt is created, and then reversing the flow. The outer annulus is filled with oil to a depth below the seat of the production casing to avoid leaching salt near the casing seat.

Test Procedures

An analysis of factors of importance to determining well leak rates from pressure tests is presented in Reference 17, and is generally the basis for procedures used for the subject tests.

The procedures, Reference 18, presume that the wells were circulated full of clean saturated brine following completion of all drilling operations, and include the following: Field lines are removed from the wellhead and blind flanges installed. The well is completely filled with saturated brine before pressurization is started (all gas accumulations in the wellhead are bled off). A digital printout pressure recorder is used to record wellhead pressures at 30 minute intervals on the hour and on the half hour. The pressure measuring system is calibrated with a dead weight tester before and after each well test. The well is pressurized to a test gradient of 0.86 psi/ft at the production casing seat. Nominal surface pressure required for this gradient is 830 psi. Maximum pressurization rate is not to exceed 25 psi/min. The well is shut in when test pressure is reached and pressures are recorded for 24 hours. At the end of the 24 hour test period, wellhead pressures are reduced to atmospheric by bleed off of brine, with depressurization rate not to exceed 25 psi/min. Should the pressure decline exceed 16 psi/hr during the first two hours of the 24 hour test period, the well is re-pressurized and the 24 hour test period re-started. Volumes of all fluid injected into the well during pressurization and recovered from the well during de-pressurization are recorded. Well elasticity (barrels per psi pressure change) is determined from the relation between measured volumes and corresponding pressure change. The rate of pressure decay (psi/hr) is determined for the last several hours of the test. The product of well elasticity and pressure decay rate is the leak rate in bbls/hr and must not exceed 0.0114 bbls/hr (0.48 gal/hr) for an allowable well leak rate of 100 bbls/yr.

Tests

In preparing for the tests following removal of field lines and the installation of blind flanges, preliminary well pressurizations were made to determine obvious wellhead leaks. During these pressurizations, a valve at the Bradenhead flange was opened to vent the annular cavity between the 20" production and 26" intermediate casings. Brine flowed from this vent valve on five of the wells while they were under pressure. In an attempt to determine the source of the leaks, a dye was added to brine injected for pressurization. On two of the wells, 107 and 110, the fluid flowing from the vent valve very soon showed traces of the dye, indicating fluid loss from the well was very near the wellhead. The most probable leak location was considered to be the threads of the 20" casing hanger. Epseal was squeezed into these threads before further testing of these wells. On the other three wells, 101, 102, and 105, the fluid flowing from the vent valve never showed any trace of dye. Subsequently on these wells, radioactive iodine was injected into the annulus between the 20" production casing and the 16" hanging string at the wellhead. The iodine was moved down hole and radioactive tracer logs were run. The tracer logs indicated leaks about 56 feet downhole in well 101, about 40 feet downhole in well 102, and about 162 feet downhole in well 105. Epseal was squeezed into the 26"-20" annuli in an effort to fill the leak path down to its Source before further testing of these wells.

On wells 112, 113 and 116, several tests were attempted in which the pressure decay rate was unacceptably high, but there was no fluid flow from the 26"-20" annulus vent valve. However, fluid flow finally started with the wells pressurized. Diagnostics similar to those described above indicated a hanger thread leak for well 113 and leaks about 40 feet down hole for wells 112 and 116. Repairs similar to those described above were made on these wells before further testing.

Results of leak tests on the above wells before the repairs were made, are not included herein.

No gas of significance was detected in any of the wells. However, methane gas was detected escaping from the annulus between the 36-inch surface casing and the 48-inch conductor casing of well 105. Epseal was squeezed into this annulus to stop the escaping methane.

Brine injected into the wells was pumped from a rectangular tank and brine recovered during depressurization was bled into a similar tank. Volumes injected and recovered were calculated from incremental measurements of brine depth in the tanks. In addition, brine volume recovered during depressurization was measured with a 1/2-inch flow meter. Cumulative volume from the flowmeter, along with pressure , was recorded at two minute intervals during the bleed off. The flow meter was not used during pressurization because of the probable adverse effects of pump pulsations on the flowmeter.

Results

Graphs of pressure versus time during the 24 hour test period are presented in Figures 2 to 16. The graphs generally indicate the pressure decay rate is maximum at the beginning of the test period and decreases to some near constant rate toward the end of the test period. Results from the Bryan Mound well tests (Reference 17) indicate similar trends, though initial decay rates were generally greater in the Bryan Mound results. These trends were theorized in Reference 17 to be associated with a reverse salt creep immediately after bringing the wellhead pressure from atmospheric to test pressure. The portion of the curves of Figures 2 to 16 that were used in the leak rate calculations are indicated by the straight line through the last several hours of test data. The pressure decay rates were determined from linear regressions of the data indicated. The pressure decay rate determined from the linear regression is obviously dependent on the data used. The data to be used was generally selected by visual determination of the last six or more hours of data which appeared to closely fit a straight line. Maximum deviations of data thus selected from the fitted curves appear to be pressures at 20.0 and 20.5 hours for well 116 (Figure 16), which immediately followed a seven hour loss of data. To determine the significance of such deviations, a second linear regression was run without the 20.0 and 20.5 hour data. The results indicated the inclusion of these two data points caused the calculated pressure decay rate, and therefore, leak rate, to be 4.9-percent higher than it would otherwise have been.

Graphs of pressure versus volume results obtained during bleed off through the flowmeter for two representative wells are presented in Figures 17 and 18. The graphs are for wells having minimum and maximum values of elasticity (volume change per unit pressure change) and are typical of data for all wells. The slope of the pressure versus volume data is maximum and generally fairly linear during withdrawal of the first 2.0 to 2.5 barrels. However, as the well pressure gets further from the test pressure and nearer to zero pressure, this slope decreases substantially. This characteristic is believed to result from well closure due to salt creep with the large change in pressure. The linear portion of the data with the straight line fairing was used for determining well elasticity for use in leak rate calculations. The slope is determined from a linear regression of the data and well elasticity is the reciprocal of this slope.

Results from tests of all the wells are summarized in Table I. Included in the table are volumes measured during pressurization and depressurization, values of well elasticity and pressure decay rate determined from the test data, and the resulting calculated leak rates.

With the exception of well 102, well elasticities from graphs similar to those of Figures 17 and 18 are shown in Table I to be within the range of 0.00405 to 0.00484 bbls/psi. These values are 11 to 33-percent above the contribution of brine compressibility for a nominal brine volume of 1660 bbls in the wells. This correlation of measured well elasticity with brine compressibility is comparable to that of the Bryan Mound well test results (Reference 17), though there is considerably less scatter in the present results. The unusually high value of elasticity for well 102 is possibly due to a higher than nominal well volume.

The bleed off volume indicated by the flow meter is on the average about 0.16 bbls less than the tank measurement volume. This result is due in part to the fact that toward the end of the bleed off, the flow rate was too low to activate the flow meter. The randomness of the differences is believed due to the relatively crude tank measurement technique.

The differences between tank measurements of volumes injected and volumes bled off is quite random. Generally, the difference is positive, as expected, but is less than would be calculated from the total pressure drop during the 24 hour test period and the experimental value of well elasticity. For wells 102, 105, 115 and 116, negative differences are indicated, a result which does not appear reasonable.

Pressure decay rates of Table I are taken directly from the Pressure time history graphs of Figures 2 to 16. The leak rates shown are the products of experimental values of well elasticities and pressure decay rates multiplied by 8760 hours per year.

It is noted that results for more than one test are shown for wells 104, 108, 110, 111, 114 and 115. All of these wells with the exception of well 104 were re-tested because the first test indicated leak rates significantly above the criterion. In all cases, the leak rate decreased in later tests. Generally, it is believed that the decrease with time of the value of calculated leak rate is due to the well having been pressurized longer before subsequent tests, with an attendant reduction in the effect of reverse salt creep following pressurization. This explanation is not believed to apply to the well 111 results, where the third and fourth tests showed substantial reductions in leak rates from those of the preceeding tests. No explanation is available for this behavior, though it is what might be expected if there was a leak path which was gradually being closed up.

Only wells 114 and 115 show leak rates for the final test in excess of the criterion. The excess leak rate for these two wells was not considered serious and a decision was made by DOE to accept them.

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3. Williams-Fenix and Scisson, "As Built Well History Report for Well 103 Located at West Hackberry Cameron Parish, Louisiana," November 7, 1980.

4. Williams-Fenix and Scisson, "As Built Well History Report for Well 104 Located at West Hackberry Cameron Parish, Louisiana," November 26, 1980.

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7. Williams-Fenix and Scisson, "As Built Well History Report for Well 107 Located at West Hackberry Cameron Parish, Louisiana," February 18, 1981.

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12. Williams-Fenix and Scisson, "As Built Well History Report for Well 112 Located at West Hackberry Cameron Parish, Louisiana," July 13, 1981.

13. Williams-Fenix and Scisson, "As Built Well History Report for Well 113 Located at West Hackberry Cameron Parish, Louisiana," January 28, 1981.

14. Williams-Fenix and Scisson, "As Built Well History Report for Well 114 Located at West Hackberry Cameron Parish, Louisiana," May 26, 1981.

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16. Williams-Fenix and Scisson, "As Built Well History Report for Well 116 Located at West Hackberry Cameron Parish, Louisiana," March 31, 1981.

17. Goin, K. L., "Analysis and Leak Tests of Wells for New Solution Mined Caverns at the Bryan Mound DOE-SPR Storage Site," SAND81-0978, April 1981.

18. Crawford, R. F., "Leak Testing of West Hackberry Strategic Petroleum Reserve Wells," Ltr., Williams-Fenix & Scisson to M. Waggoner, DOE-SPR, dtd 3/20/81.

Distribution:

US Department of Energy
Strategic Petroleum Reserve
Project Management Office
900 Commerce Road East
New Orleans, LA 70123
Attn: E. E. Chapple (5)
C. C. Johnson
G. A. Stafford
C. L. Steinkamp

US Department of Energy
Strategic Petroleum Reserve
1000 'Independence Avenue SW
Washington, DC 20585
Attn: L. Pettis
R. Smith

Aerospace Corporation
880 Commerce Road West, Suite 300
New Orleans, LA 70123
Attn: K. Henrie
R. Merkle

Aerospace Corporation
P. 0. Box 92957
Los Angeles, CA 90009
Attn: G. F. Kuncir

Dravo Utility Constructors, Inc.
850 S. Clearview Pkwy.
New Orleans, LA 70123
Attn: J. M. **Blazier** (2)

Dravo Utility Constructors, Inc.
P. 0. Box 278
West Hackberry, LA 70645
Attn: Ray Bradley (2)

Jacobs/D'Appolonia Engineers
6226 Jefferson Hwy., Suite B
New Orleans, LA 70123
Attn: H. Kubicek
P. Campbell

Williams, Fenix **& Scisson**
800 Commerce Road West
New Orleans, LA 70123
Attn: Robert Crawdford

4000 A. Narath
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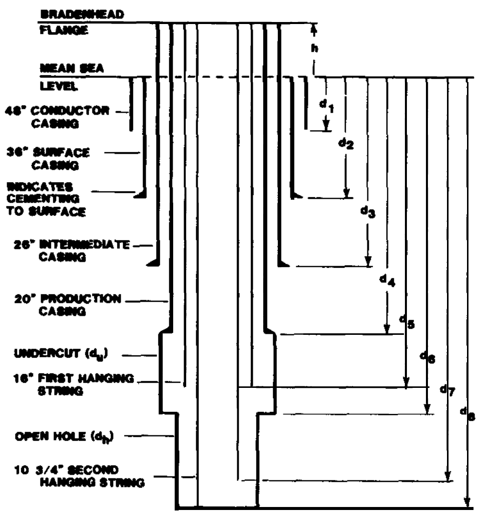
TABLE I - SUMMARY OF TEST RESULTS

Well	Test Date	Measured Volume, BBLS Required To Pressurize	Measured Volume, BBLS Required During Bleed Off	Bleed Off Volume, BBLS Indicated by Flow Meter	Well Elasticity BBLS/PSI	Pressure Decay/Rate Psi/Hr	Leak Rate BBLS/YR
101	5/3	4.834	4.679	3.143	0.00437	1.676	64
102	5/11	4.835	4.985	4.976	.00542	0.139	7
103	4/5	3.600	3.555	3.690	.00441	0.664	26
104	4/4		4.964	4.810	.00462	1.504	61
104	4/5	4.671	4.643	4.524	.00474	1.327	55
105	5/12	3.535	3.665	3.690	.00405	1.385	49
106A	No Test						
107	5/5	6.862	5.460	5.286	.00484	1.342	57
108	4/6	3.800	3.395	3.548	.00454	3.213	128
108	4/8	3.791	3.719	3.714	.00449	2.419	95
109	4/10	3.888	3.743	3.952	.00450	1.699	67
110	5/6	5.838	3.587	3.333	.00425	2.971	111
110	5/8	4.054	3.650	3.405	.00444	2.805	109
110	5/10	4.483	3.819	3.524	.00432	2.465	93
111	4/17	4.248	4.179	3.952	.00438	3.885	149
111	4/19	4.205	4.060	3.595	.00443	4.273	166
111	5/14	4.482	3.782	3.762	.00433	3.110	118
111	5/16	3.996	3.899		.00431	1.797	68
112	5/21			4.143	.00456	0.449	18
113	5/22			3.929	.00432	1.944	74
114	4/17	3.664	3.507		.00437	3.163	121
114	5/10	3.725	3.561	3.286	.00444	2.684	104
114	5/12	3.471	3.405	3.357	.00444	2.799	109
115	4/8	3.524	3.655	3.833	.00458	3.807	153
115	4/11	3.598	3.540			2.815	112
115	4/13	3.772	3.656	3.690	.00451	2.880	114
116	5/20	4.502	4.510	4.143	.00459	1.642	66



NOTE: SURFACE CASING 30" FOR WELLS 102 AND 104

		DIMENSIONS - FEET										DIAMETER - INCHES	
WELL	h	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_c	d_s	d_u	d_h
101	20.1	76	1564	2141	2412	2782	2785	4941	5005	1589	2030	22	18 1/2
102	17.5	65	1587	2143	2422	2769	2830	4951	5017	1603	2045	22	18 1/2
103	17.8	84	1570	2154	2413	2767	2782	4922	5026	1540	2020	22	18 1/2
104	19.2	64	1514	2074	2423	2806	2806	4953	5014	1542	2057	22	17 1/2
105	19.1	88	1580	2145	2434	2802	2805	4933	5020	1628	2039	22	17 1/2
106A	17.5	82	1607	2192	2383	2694	*	5005	5111	1641	2048	*	28
107	16.3	84	1624	2179	2454	2770	2856	4923	5015	1591	2041	22	17 1/2
108	8.2	96	1611	2144	2400	2769	2770	4966	5020	1656	2045	22	18 1/2
109	11.0	90	1209	2132	2458	2889	2861	4916	5056	1595	2046	22	17 1/2
110	8.3	90	1669	2169	2422	2782	2783	4946	5013	1675	2064	22	17 1/2
111	8.1	112	1877	2296	2525	2885	2899	4941	5023	1971	2171	22	18 1/2
112	9.0	87	1663	2213	2428	2856	-	4933	5015	1641	2041	17 1/2	17 1/2
113	8.0	98	1813	2231	2760	3129	3133	4984	5040	1912	2105	22	18 1/2
114	7.9	71	1698	2217	2440	2799	-	4945	5015	1660	2065	17 1/2	17 1/2
115	9.6	77	1684	2191	2438	2895	2915	4947	5020	1704	2064	22	17 1/2
116	8.2	94	1465	2220	2501	2931	3061	4933	5011	1764	2079	22	17 1/2

d_c - DEPTH FROM MEAN SEA LEVEL TO TOP OF CAPROCK
d_s - DEPTH FROM MEAN SEA LEVEL TO TOP OF SALT
* - 79 FEET OF 20" CASING LODGED BETWEEN DEPTHS OF 2690 AND 2769 FEET

Figure 1 – Well Geometries

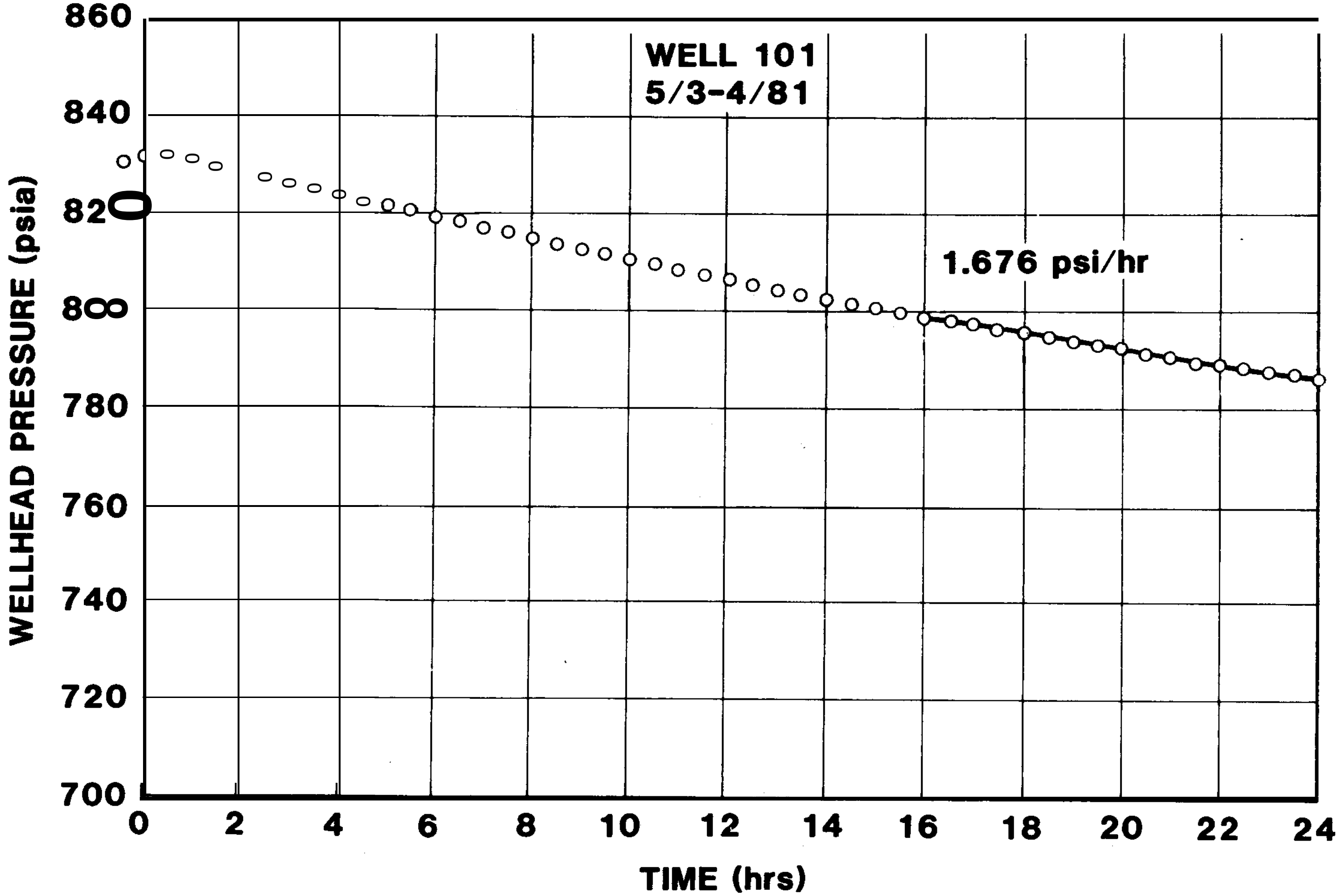


Figure 2 - Pressure-Time
History for Well 101

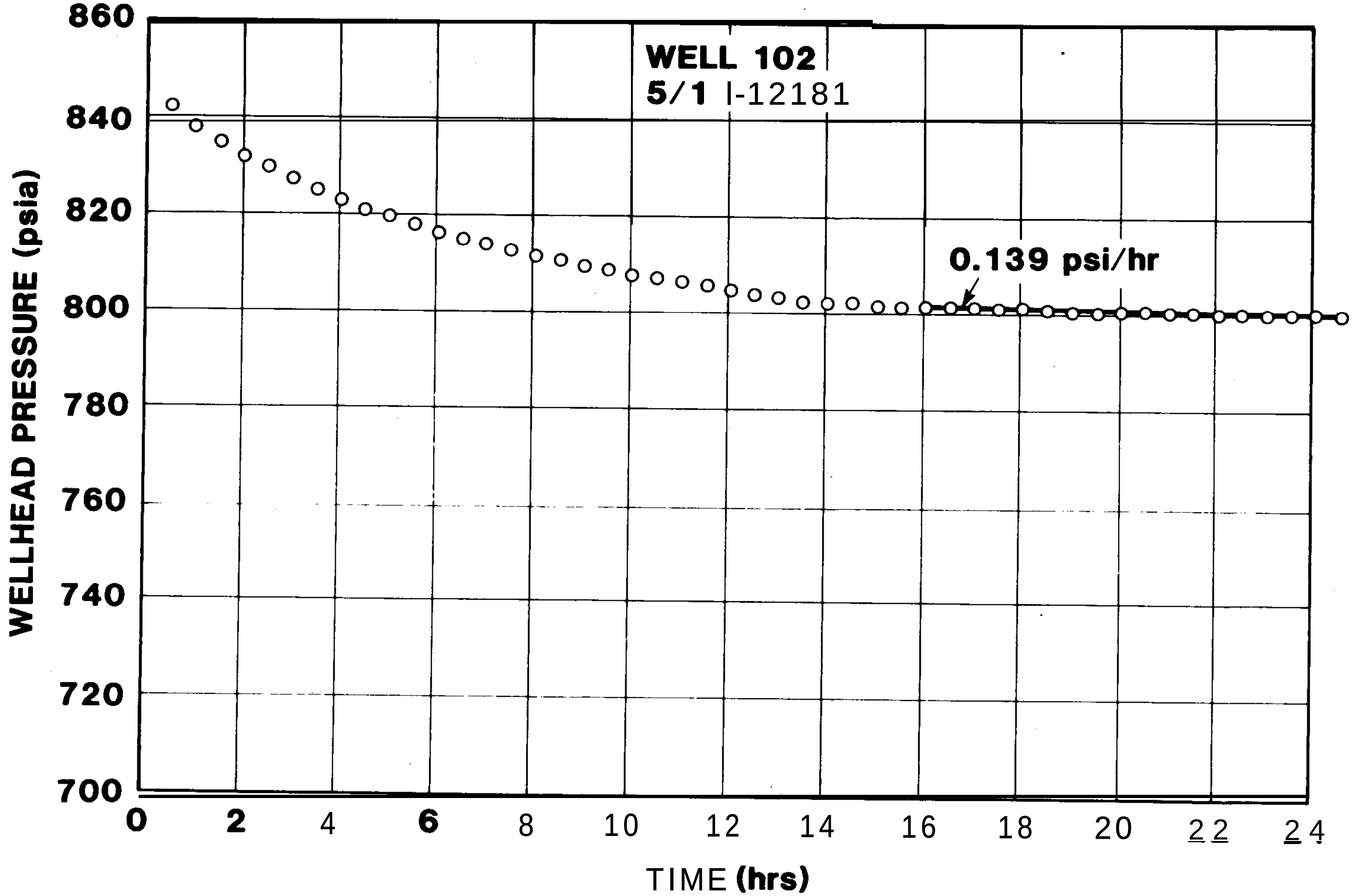


Figure 3 – Pressure-Time History for Well 102

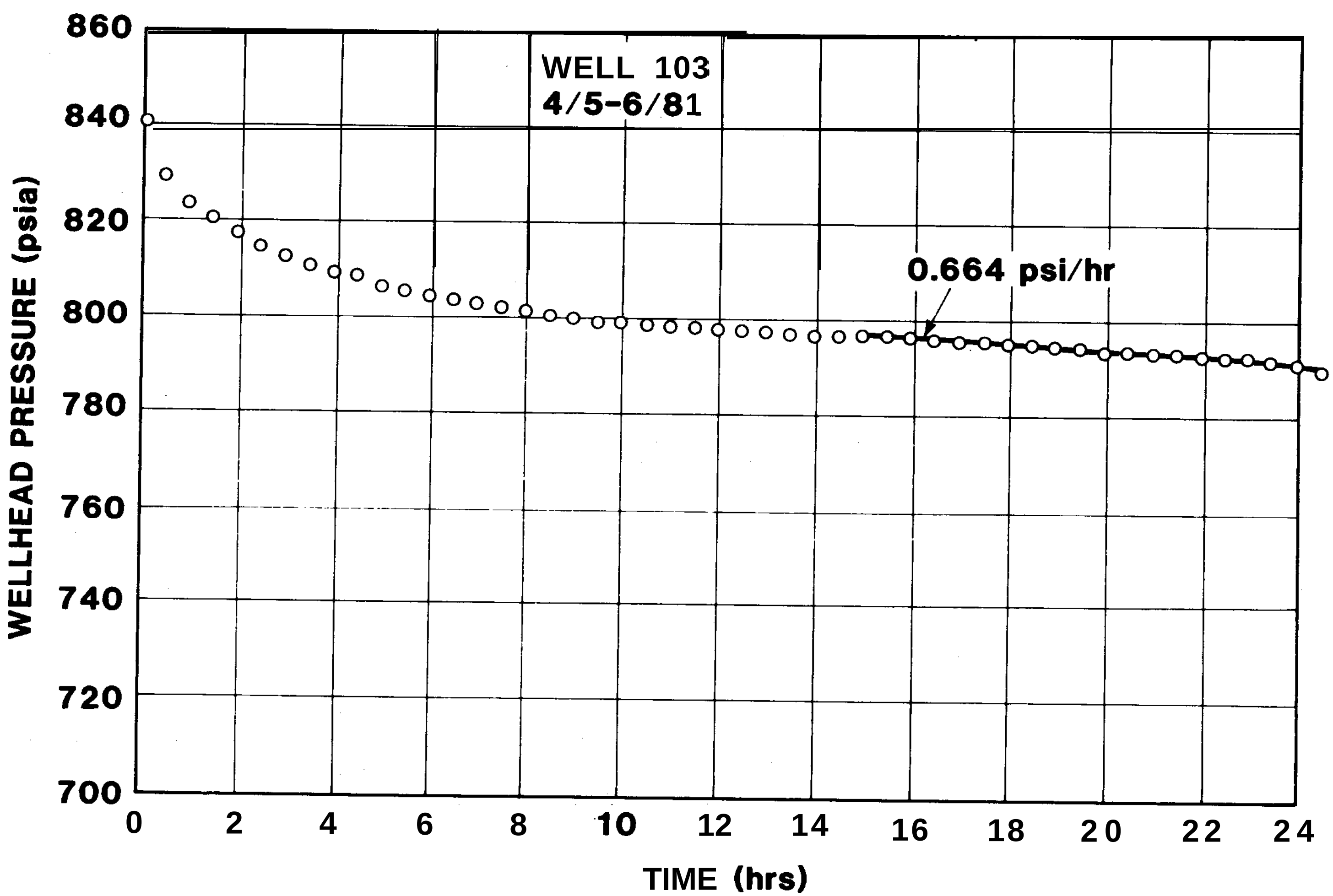


Figure 4 - Pressure-Time
History for Well 103

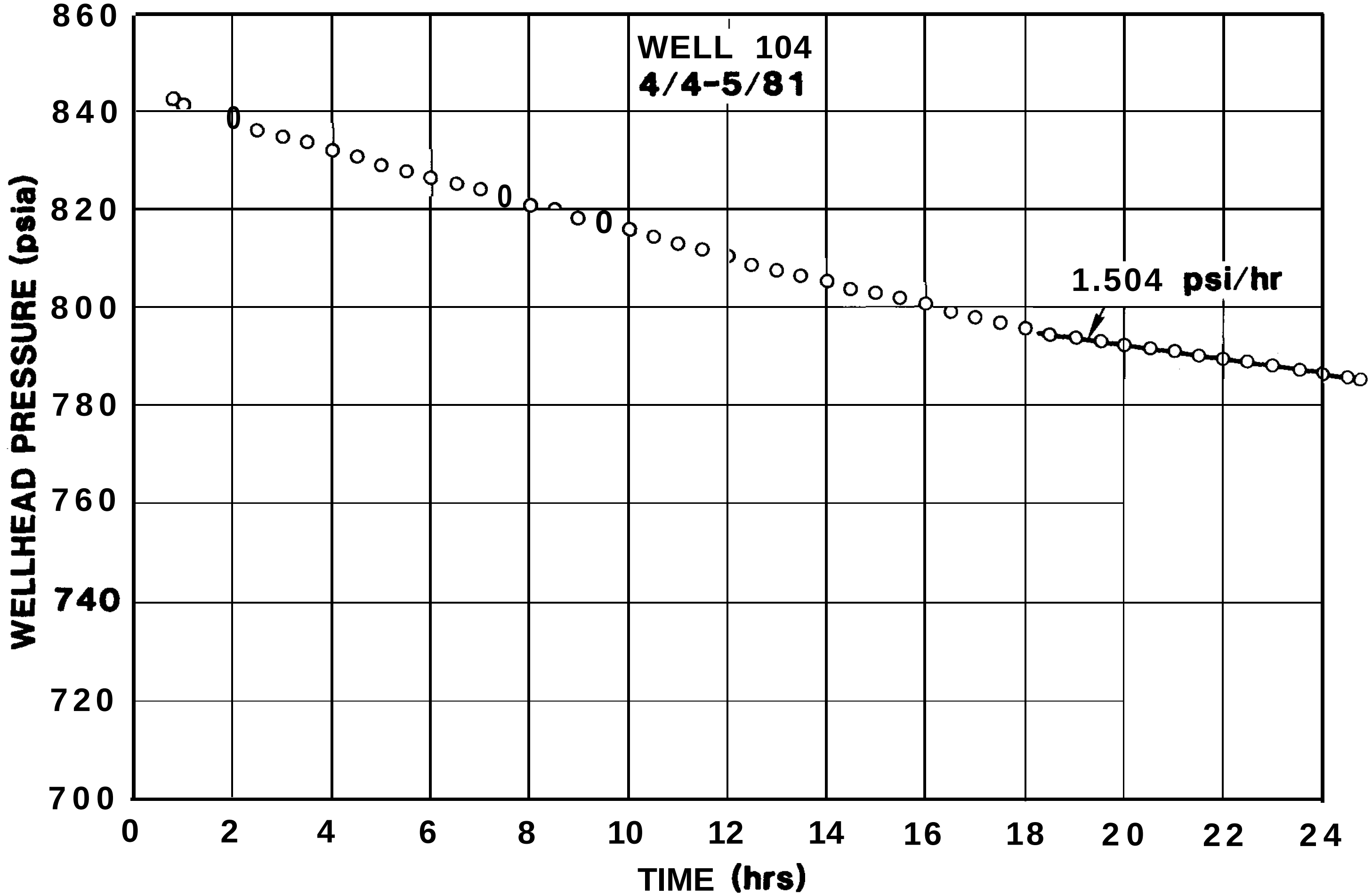


Figure 5a – Pressure-Time
History for Well 104

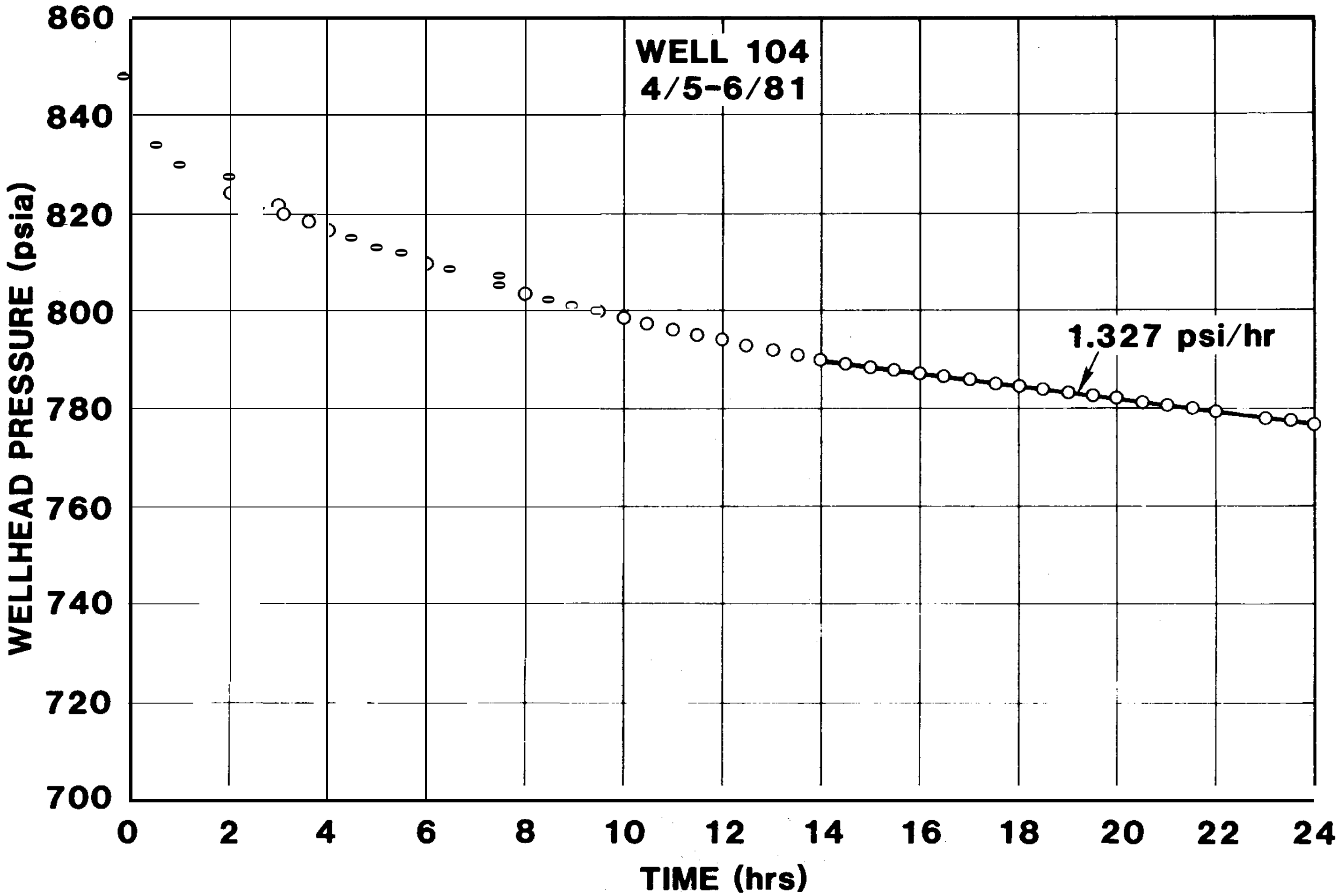

WELL 104
4/5-6/81
1.327 psi/hr
WELLHEAD PRESSURE (psia)
860
840
820
800
780
760
740
720
700
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME (hrs)

Figure 5b

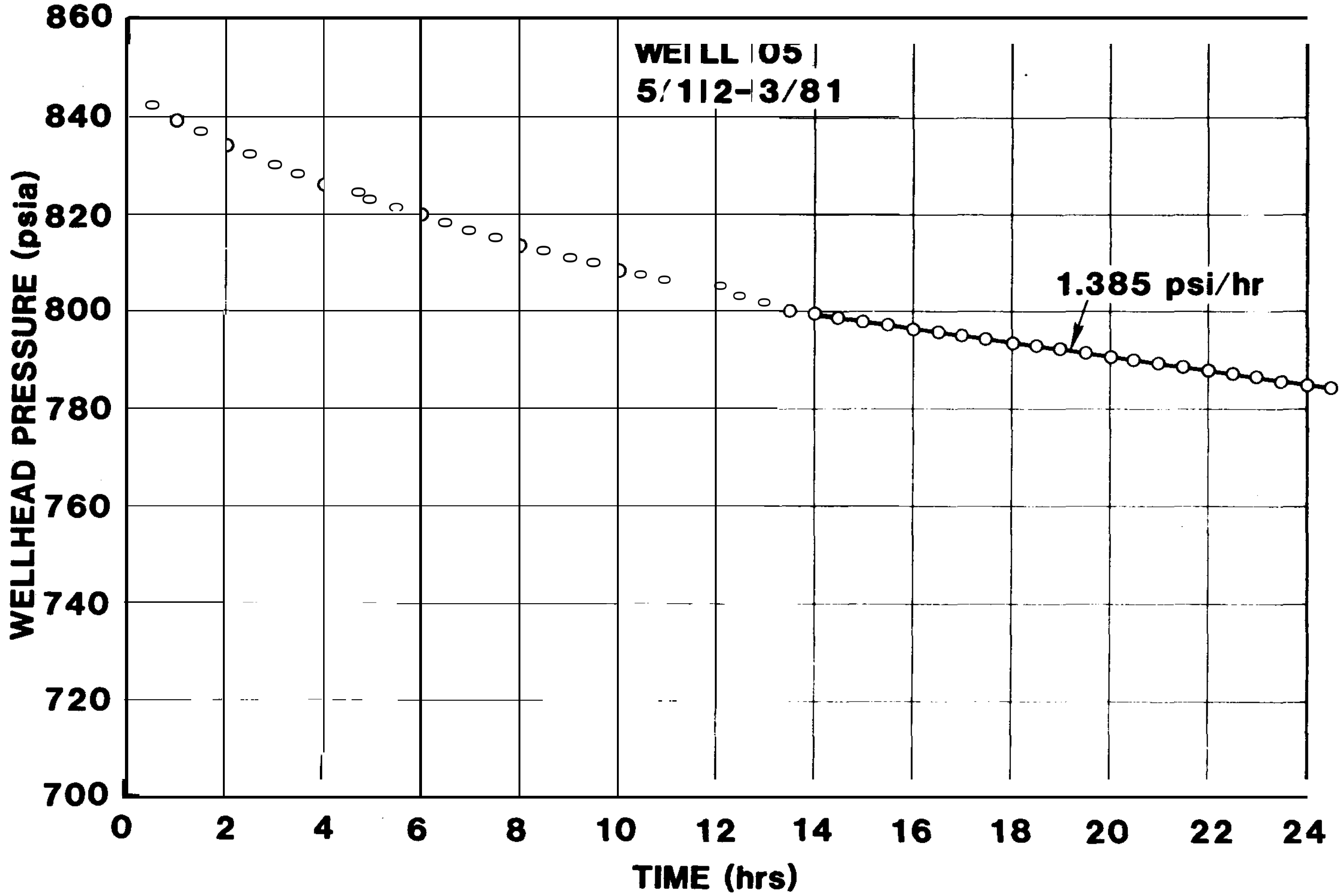


Figure 6 - Pressure-Time
History for Well 105

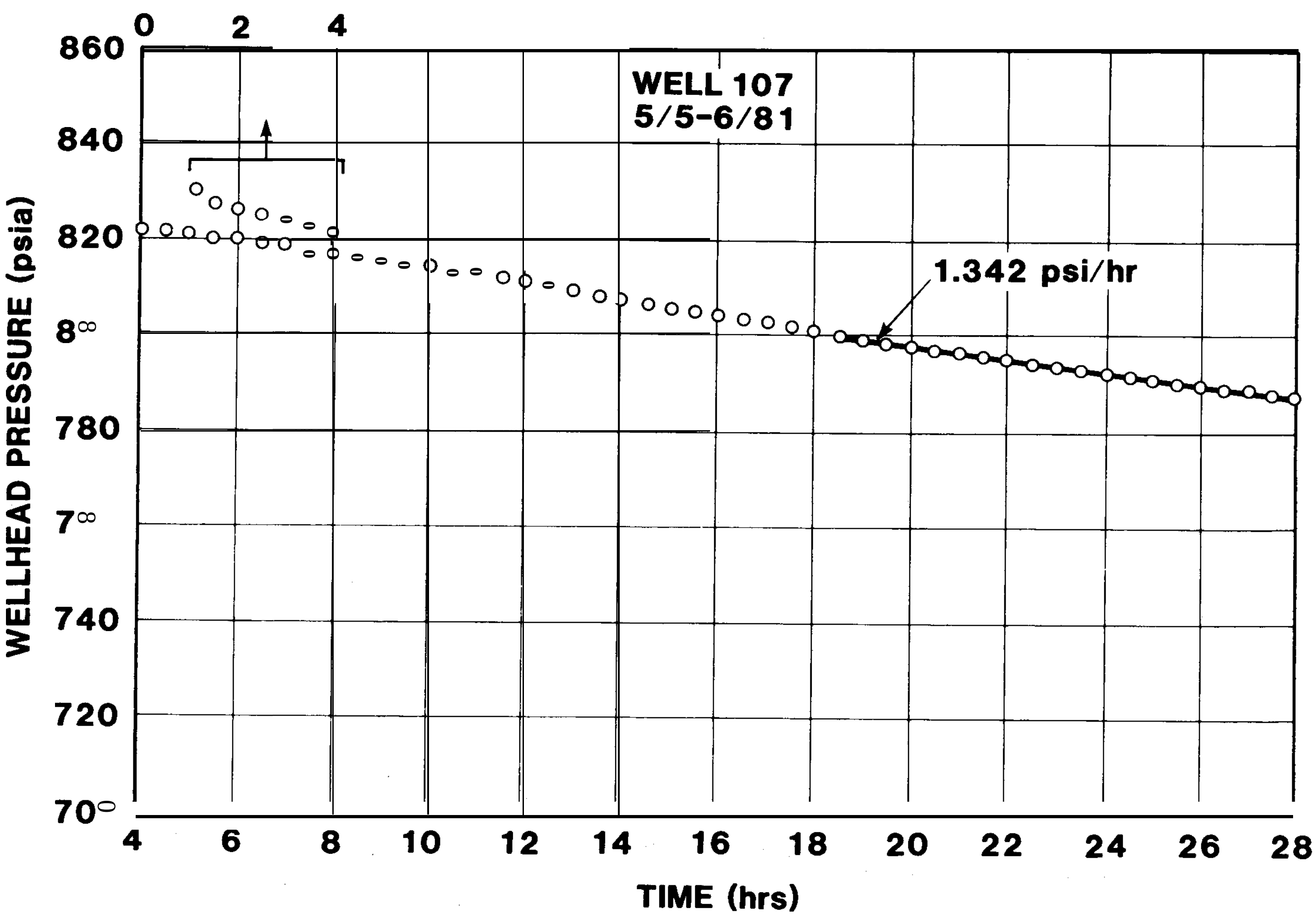


Figure 7 - Pressure-Time
History for Well 107

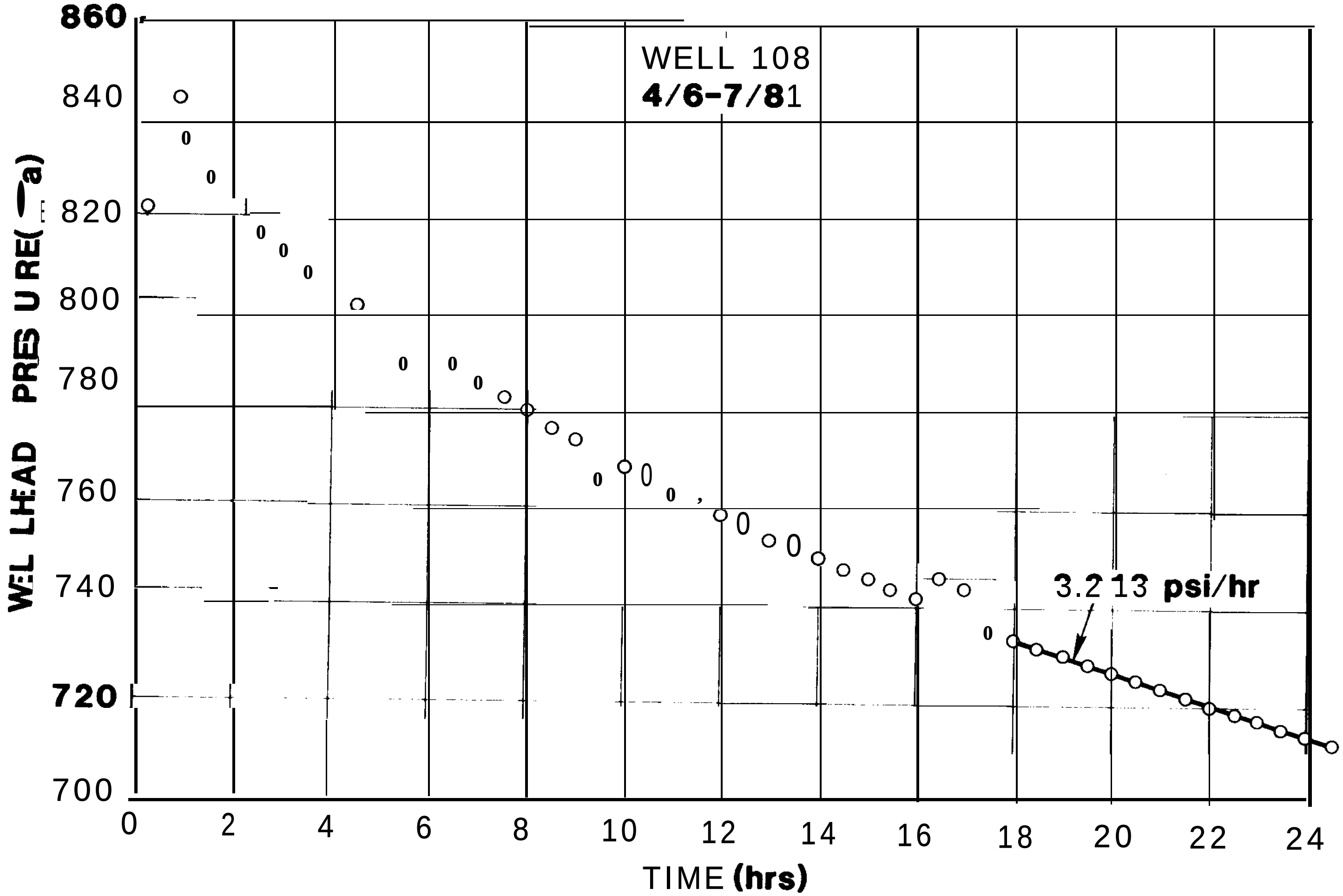


Figure 8a - Pressure-Time History for Well 108

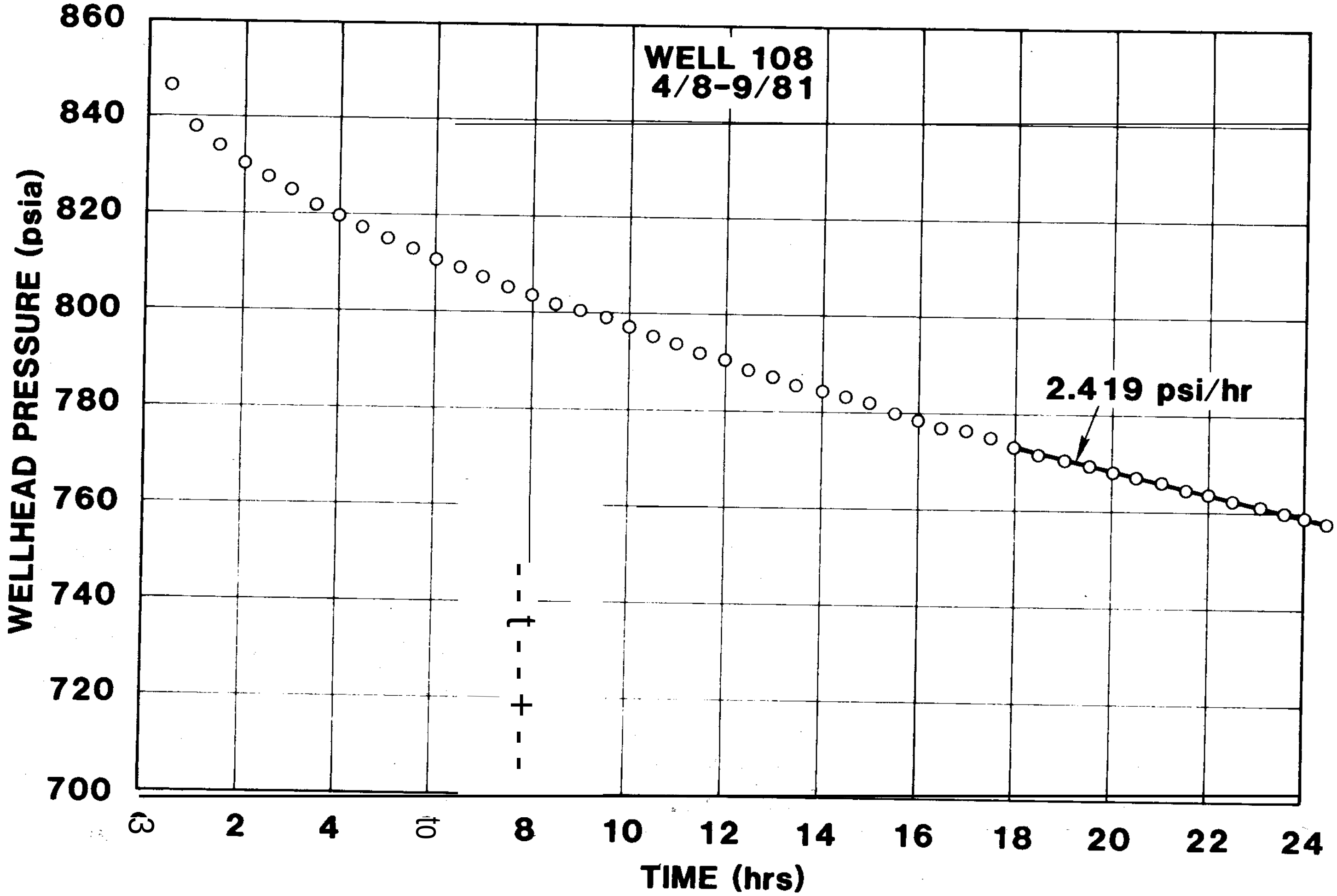

WELL 108
4/8-9/81
2.419 psi/hr
WELLHEAD PRESSURE (psia)
860
840
820
800
780
760
740
720
700
2
4
8
10
12
14
16
18
20
22
24
TIME (hrs)

Figure 8b

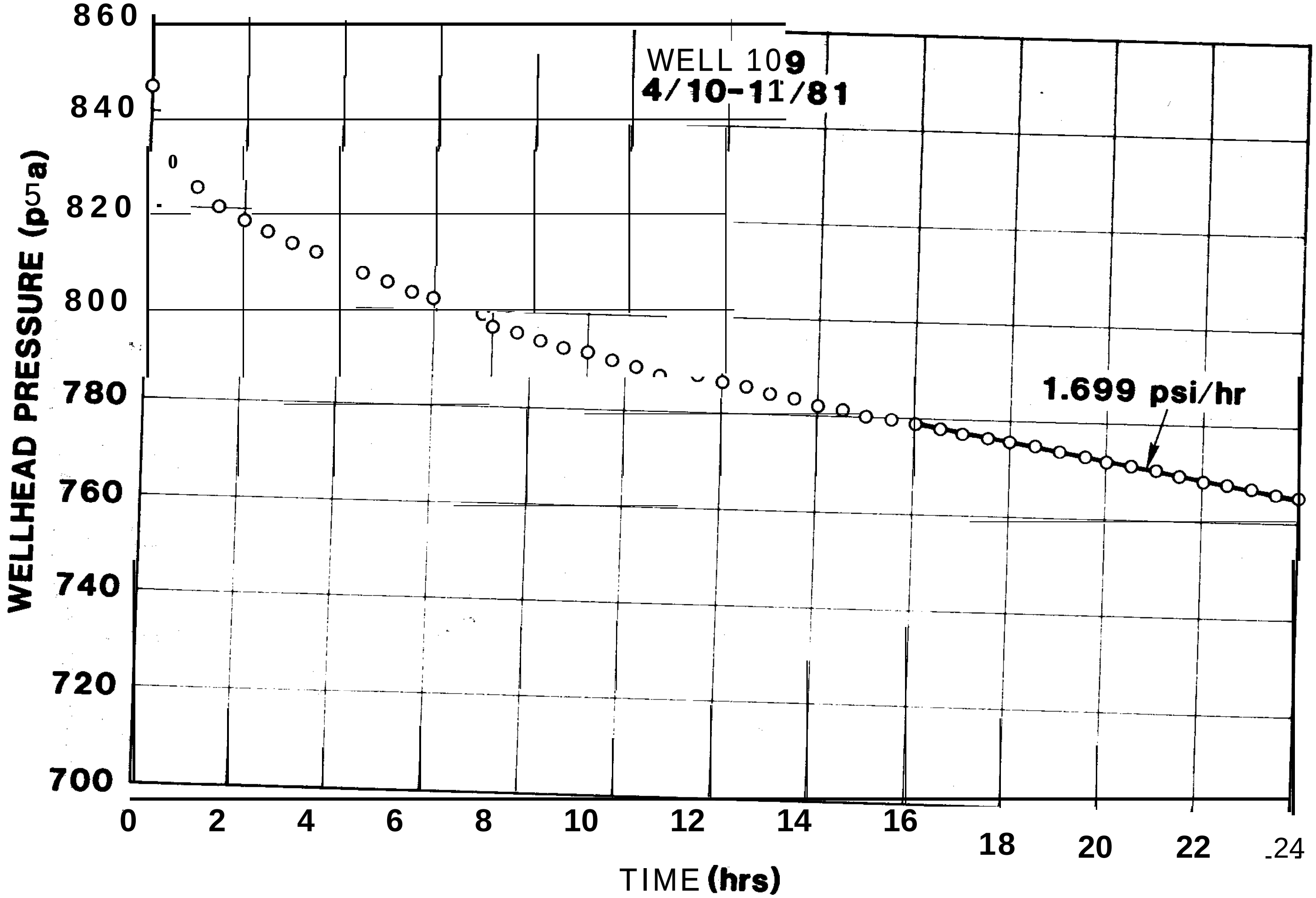


Figure 9 – Pressure-Time History for Well 109

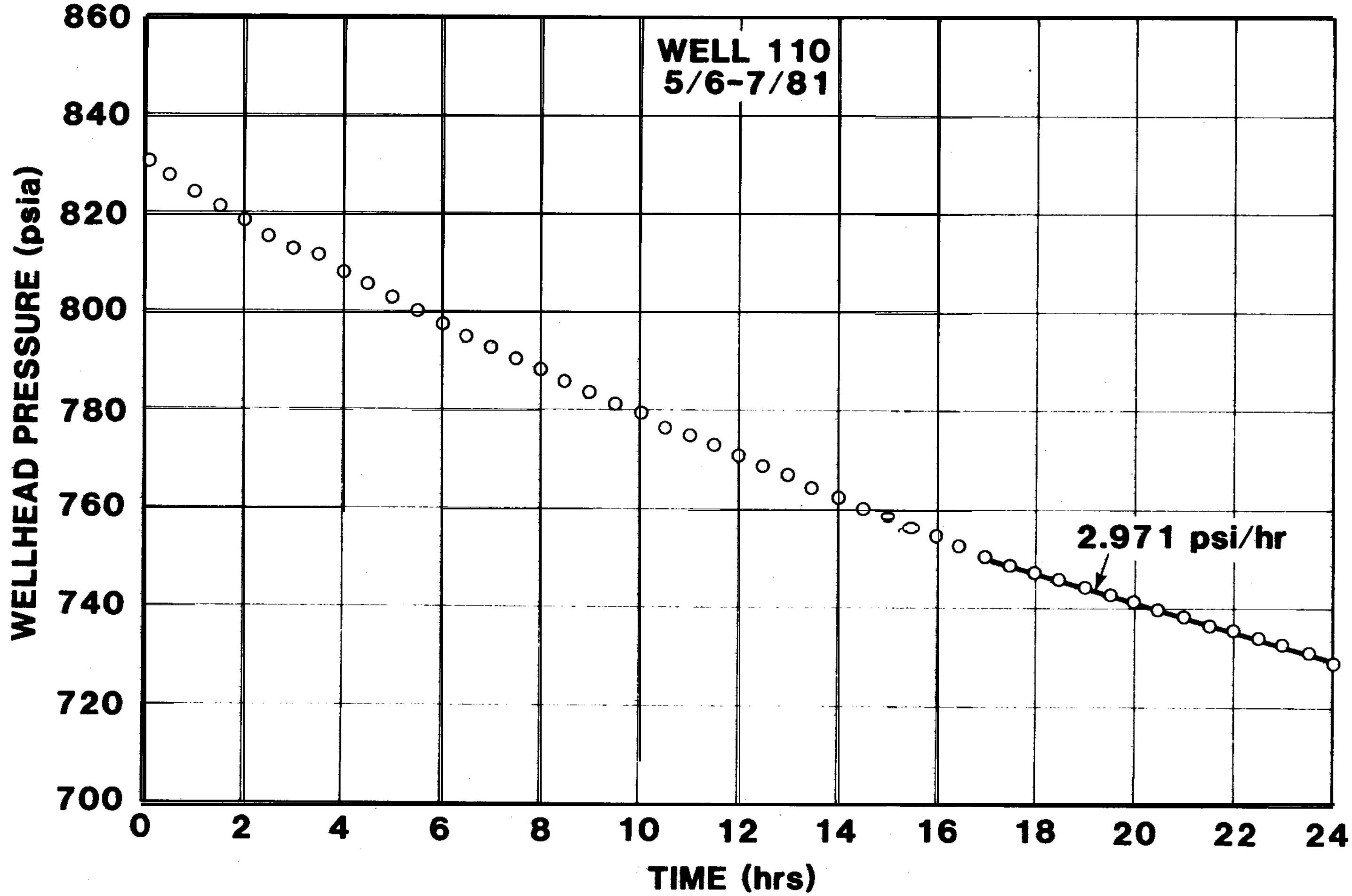
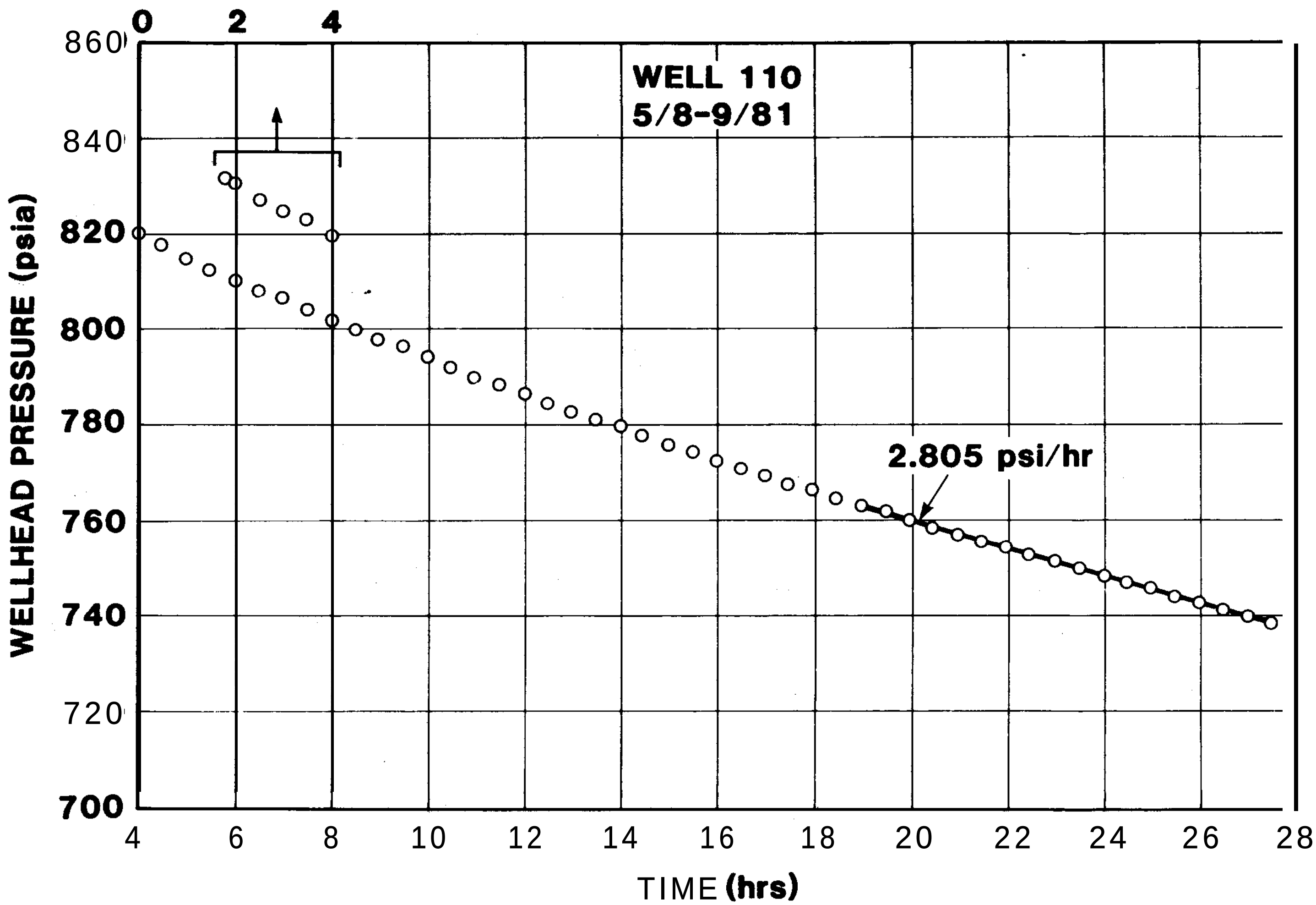


Figure 10a - Pressure-Time History for Well 110



0
2
4
860
840
820
800
780
760
740
720
700
WELL 110
5/8-9/81
2.805 psi/hr
WELLHEAD PRESSURE (psia)
4
6
8
10
12
14
16
18
20
22
24
26
28
TIME (hrs)

Figure 10b

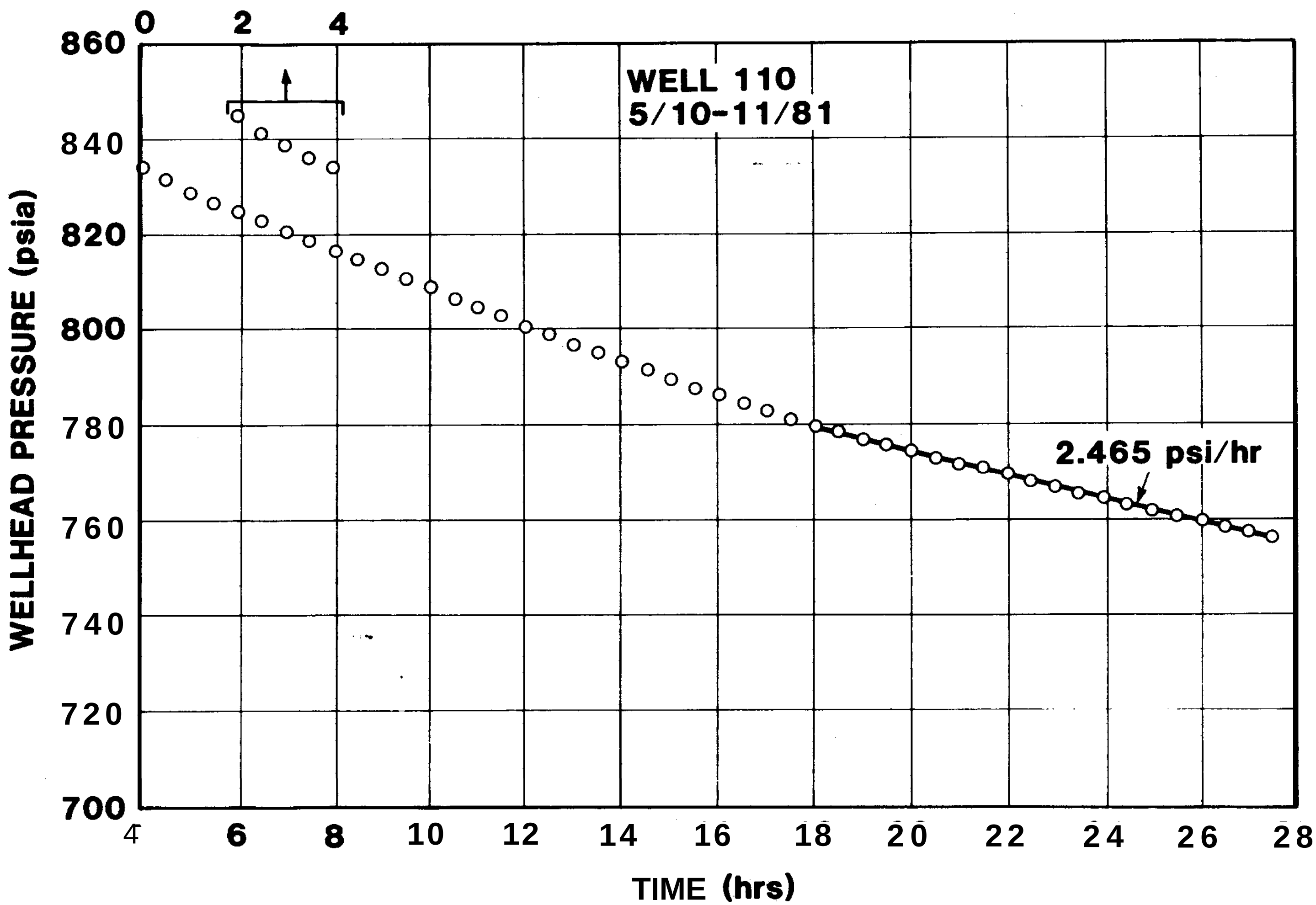

WELL 110
5/10-11/81
2.465 psi/hr
WELLHEAD PRESSURE (psia)
TIME (hrs)
0
2
4
860
840
820
800
780
760
740
720
700
4
6
8
10
12
14
16
18
20
22
24
26
28

Figure 10c

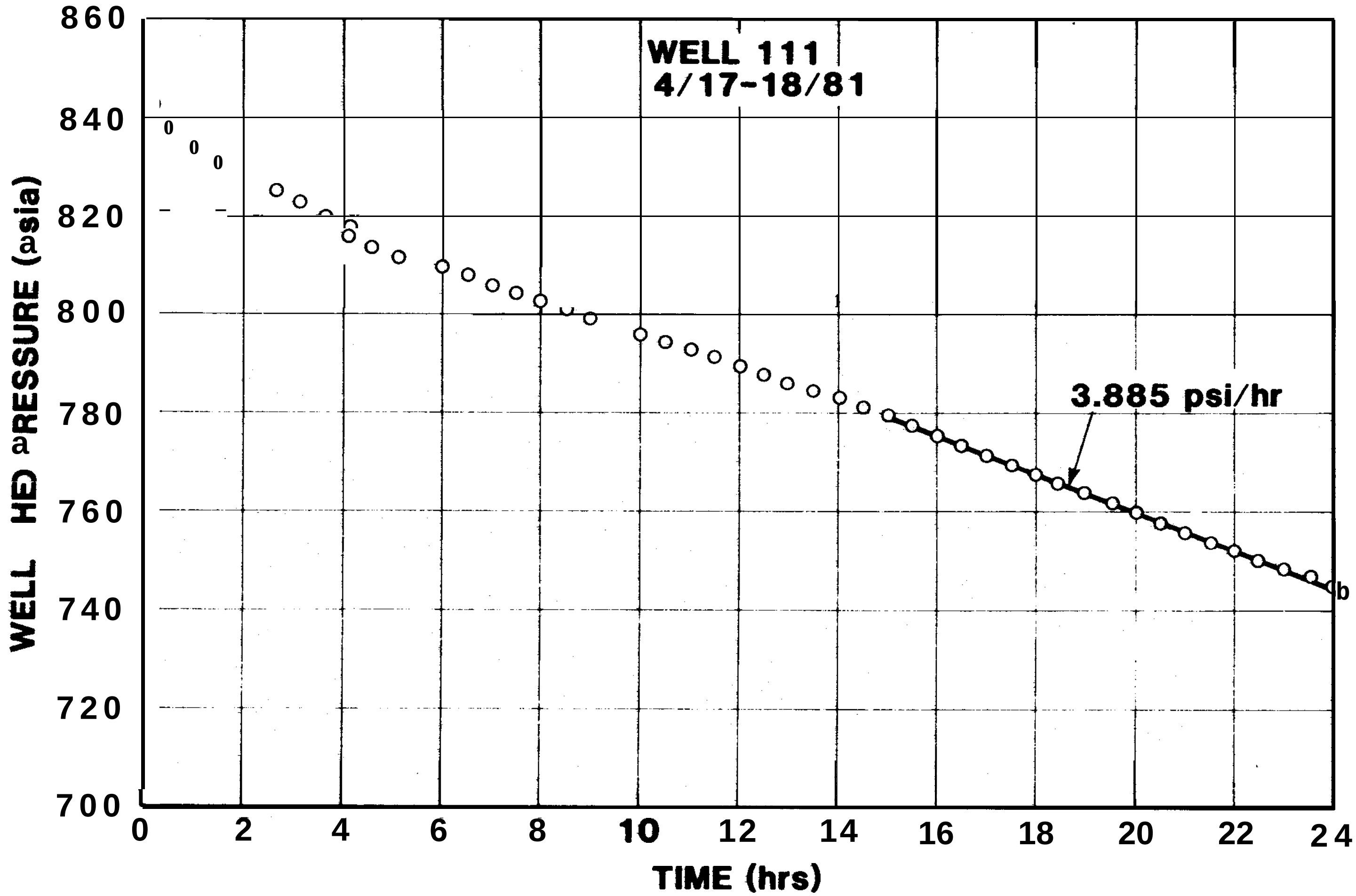


Figure 11a - Pressure-Time History for Well 111

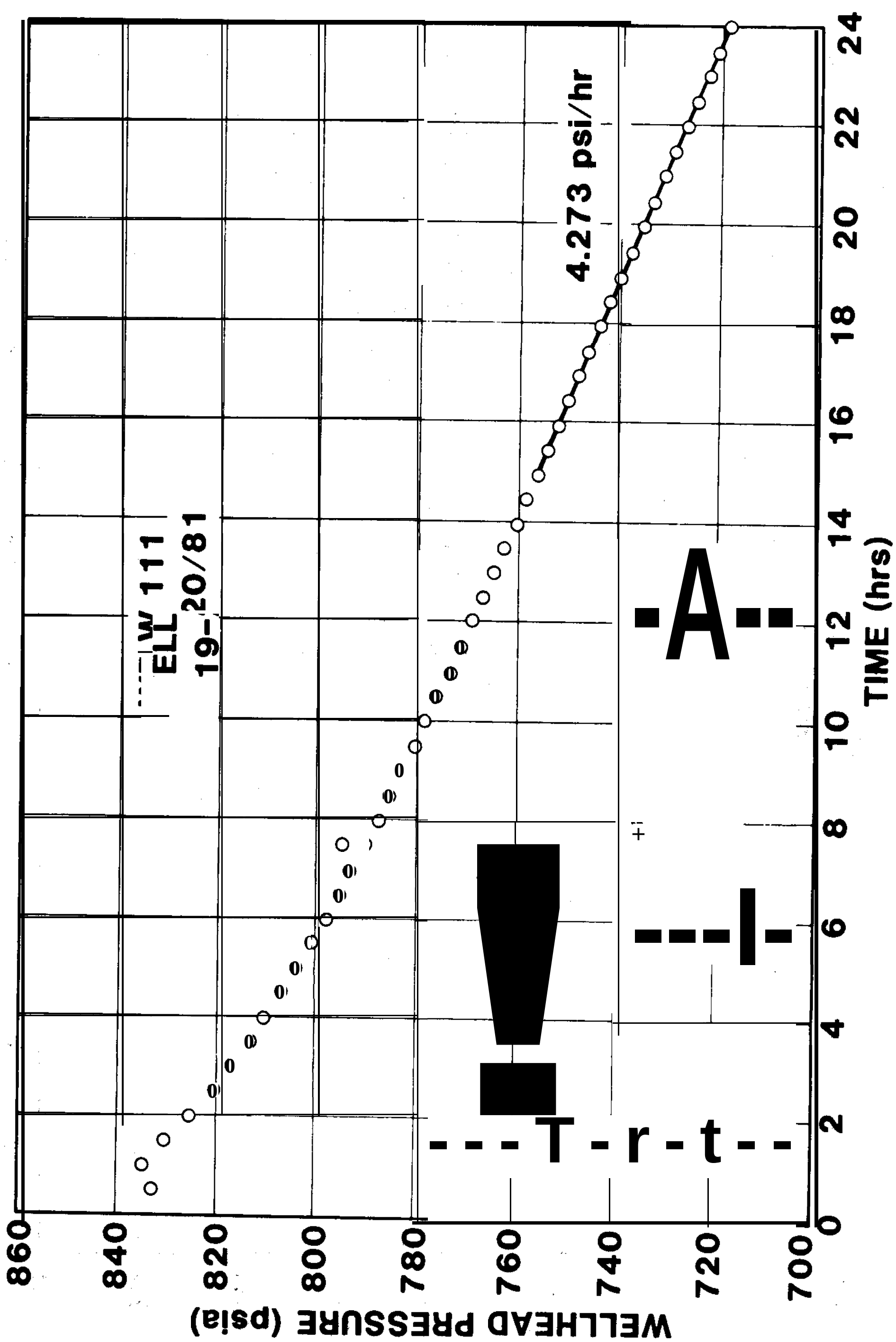

4.273 psi/hr
TIME (hrs)
WELLHEAD PRESSURE (psia)
0 2 4 6 8 10 12 14 16 18 20 22 24
700 720 740 760 780 800 820 840 860

Figure 11b

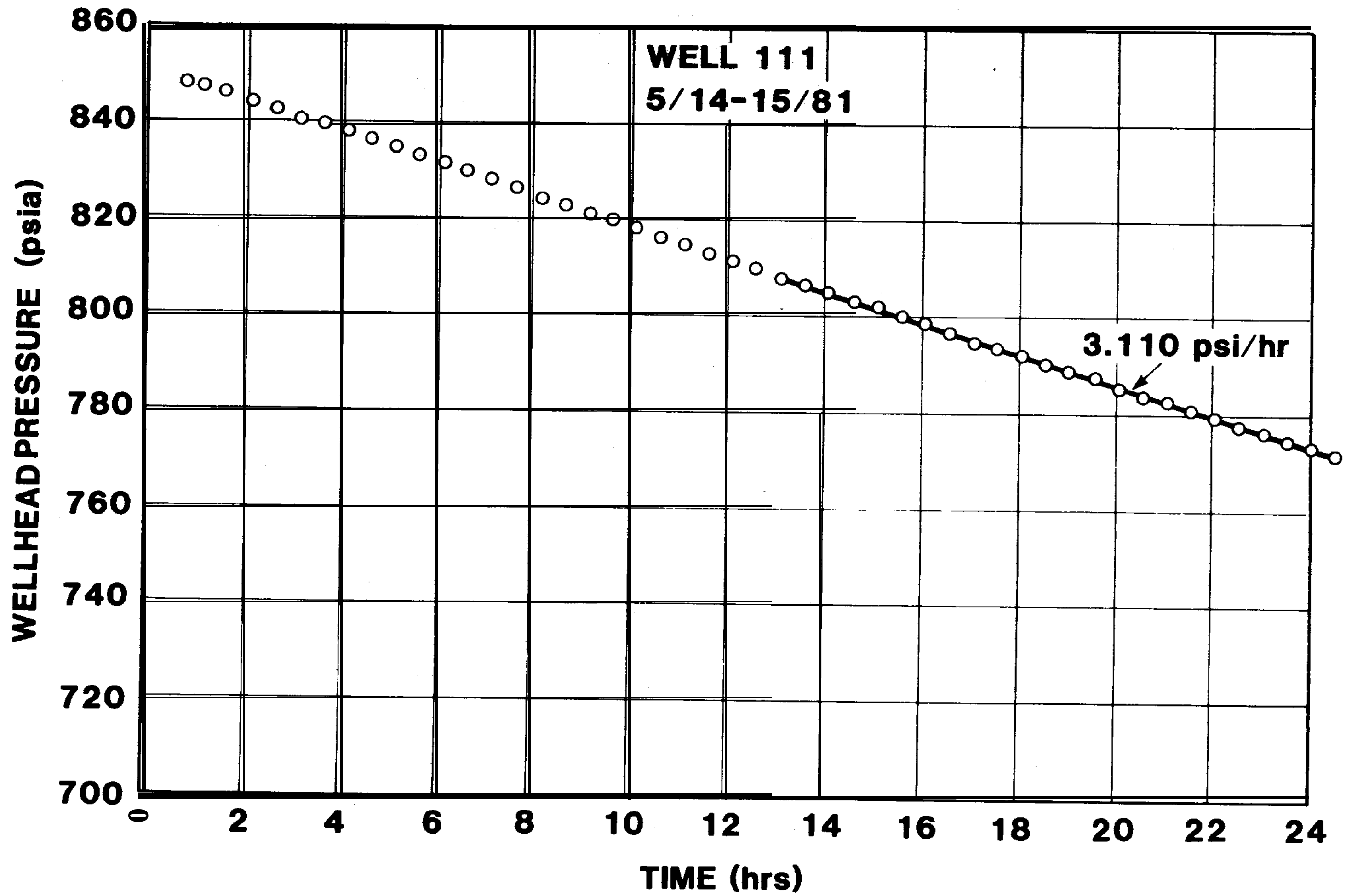

WELL 111
5/14-15/81
3.110 psi/hr
WELLHEAD PRESSURE (psia)
860
840
820
800
780
760
740
720
700
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME (hrs)

Figure 11c

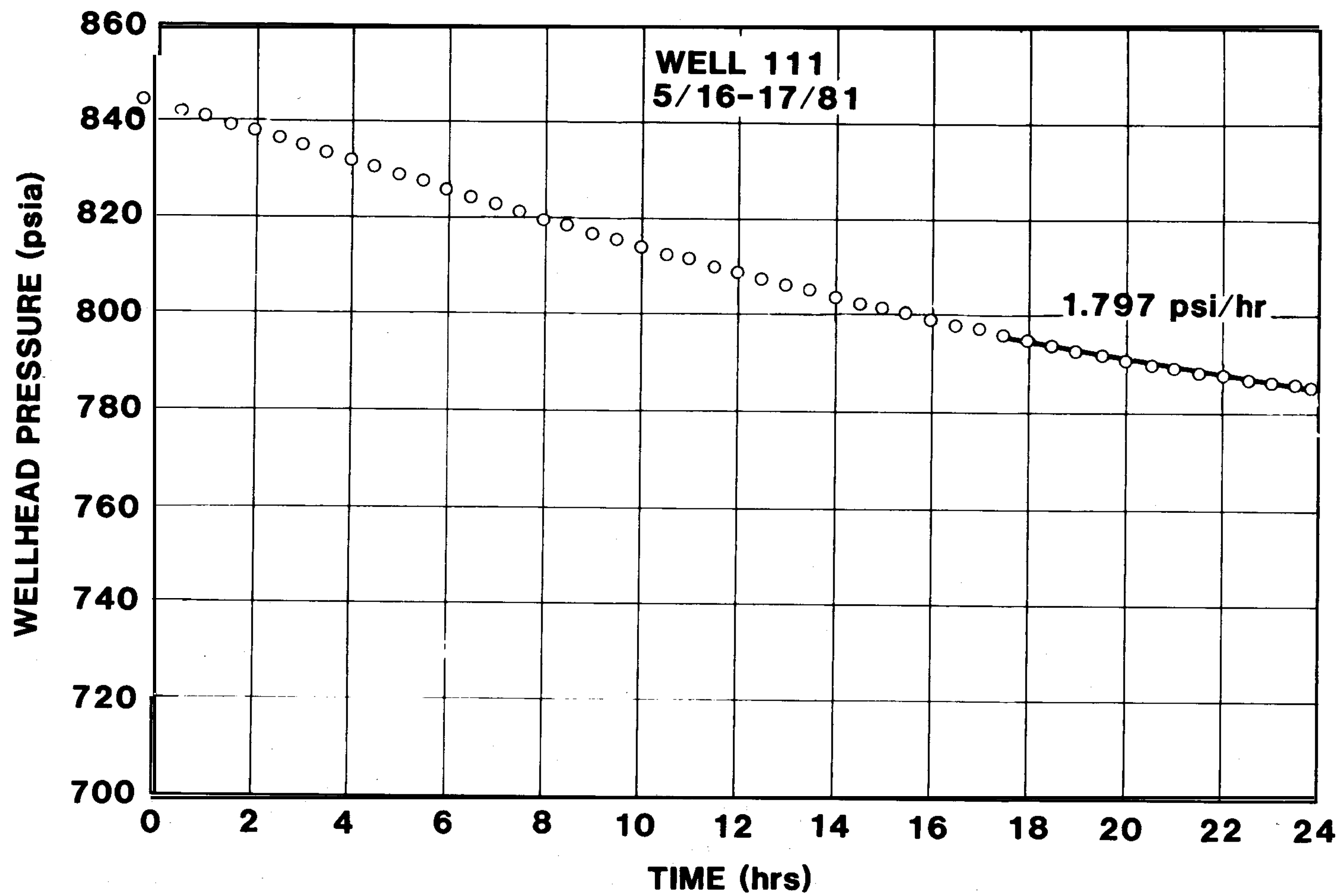

WELL 111
5/16-17/81
1.797 psi/hr
WELLHEAD PRESSURE (psia)
860
840
820
800
780
760
740
720
700
TIME (hrs)
0
2
4
6
8
10
12
14
16
18
20
22
24

Figure 11d

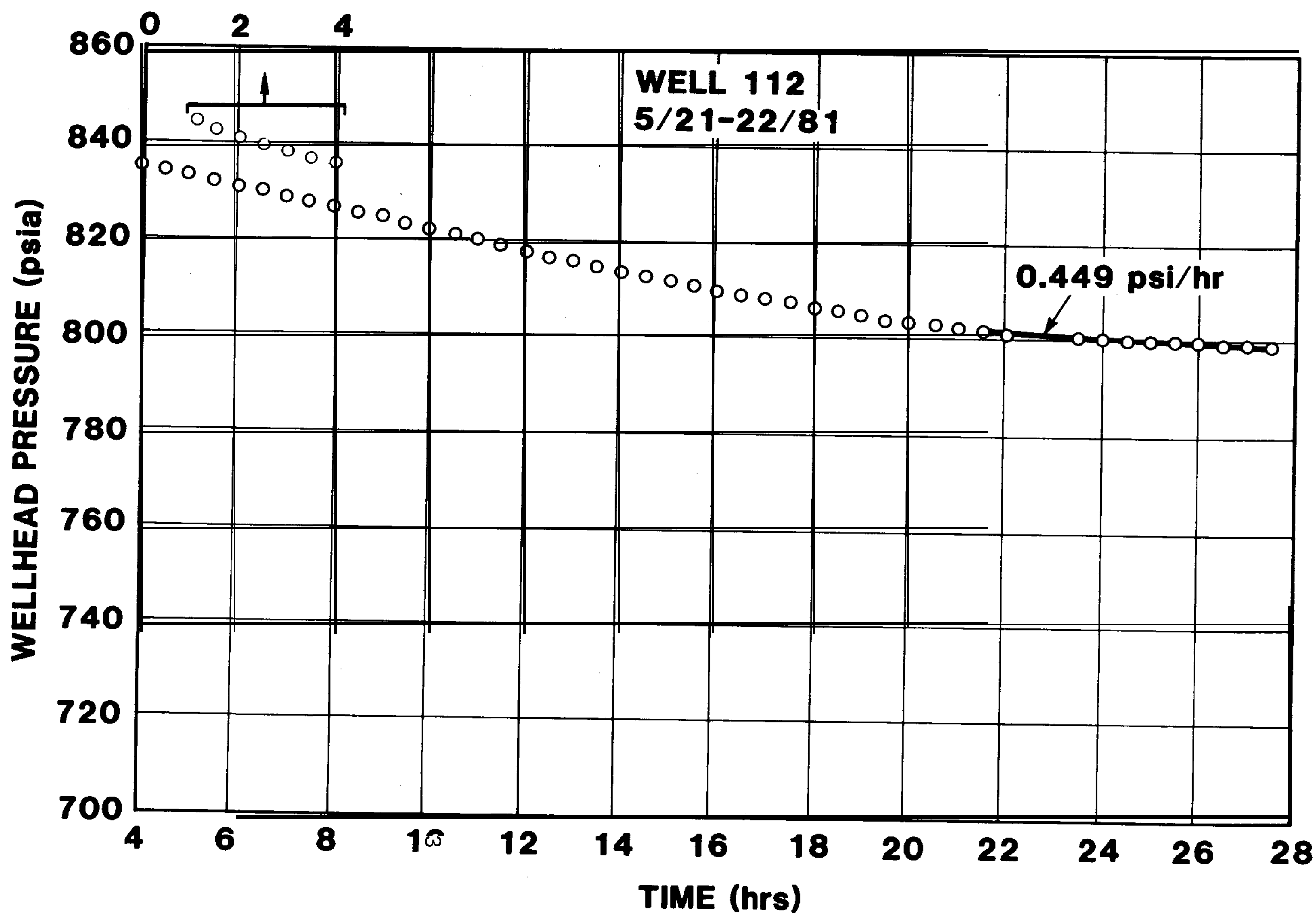


Figure 12 - Pressure-Time History for Well 112

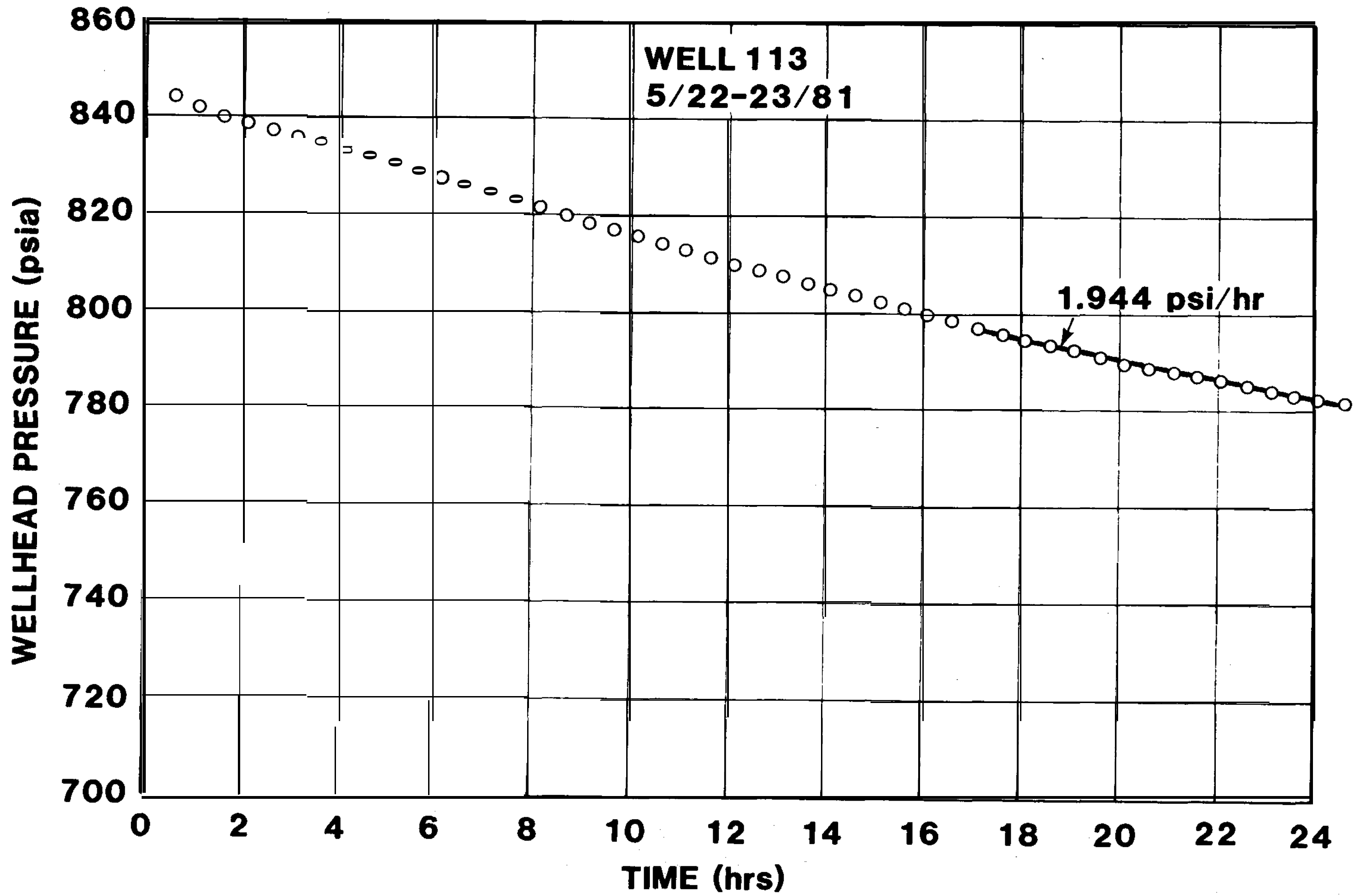


Figure 13 - Pressure-Time History for Well 113

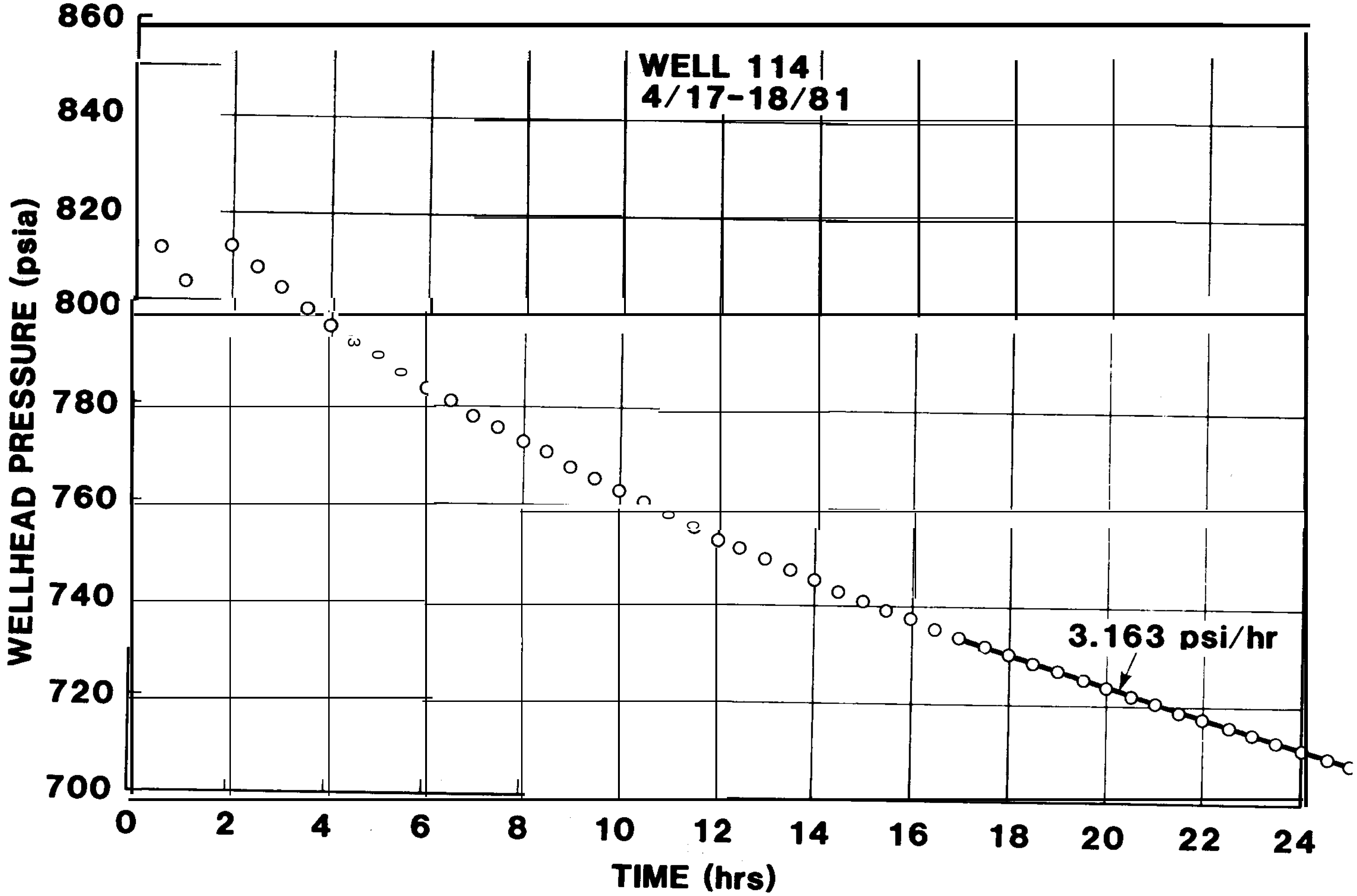


Figure 14a - Pressure-Time
History for Well 114

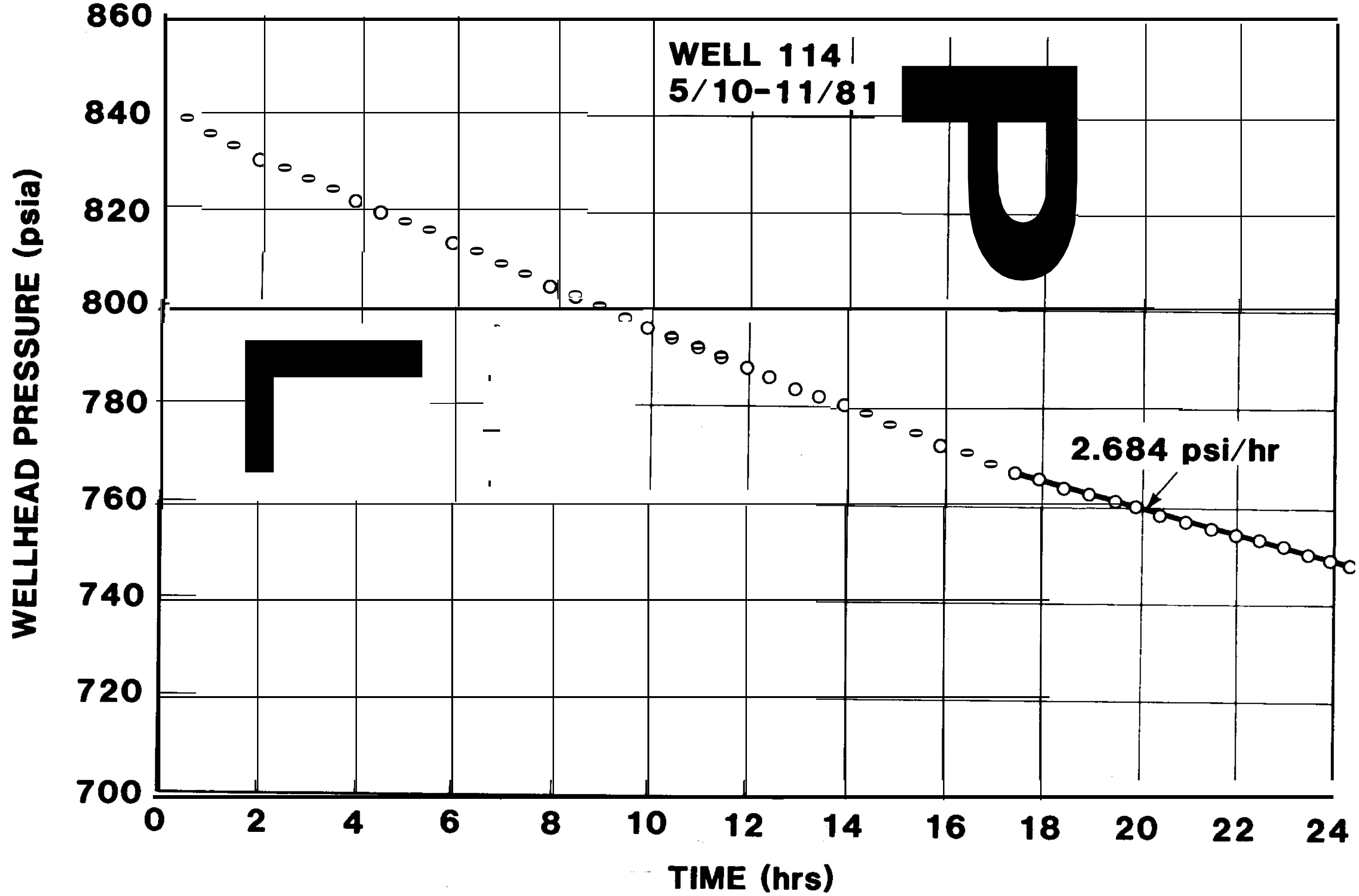

WELL 114
5/10-11/81
P
L
2.684 psi/hr
WELLHEAD PRESSURE (psia)
860
840
820
800
780
760
740
720
700
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME (hrs)

Figure 14b

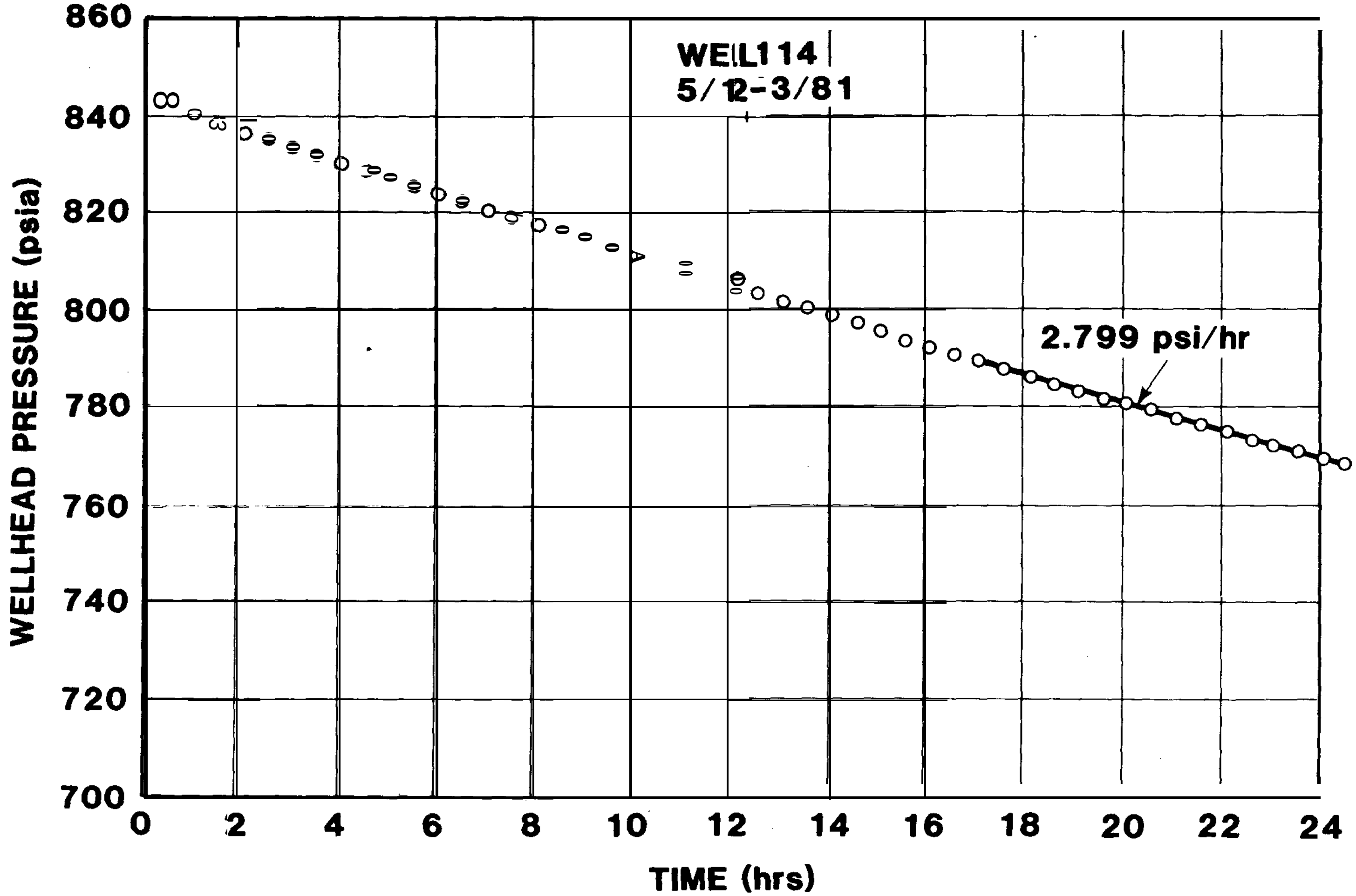

WELL114
5/12-3/81
2.799 psi/hr
WELLHEAD PRESSURE (psia)
860
840
820
800
780
760
740
720
700
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME (hrs)

Figure 14c

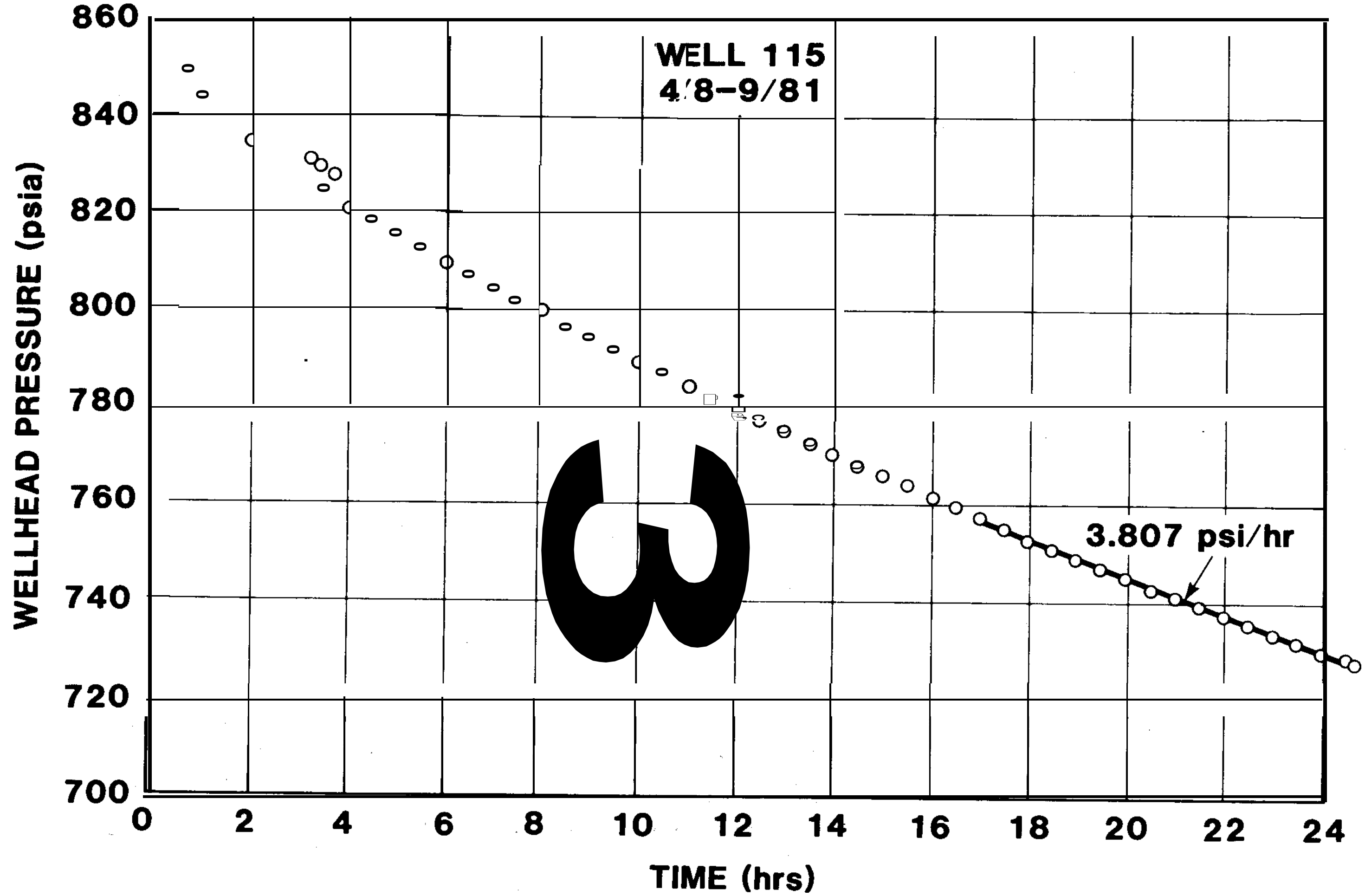
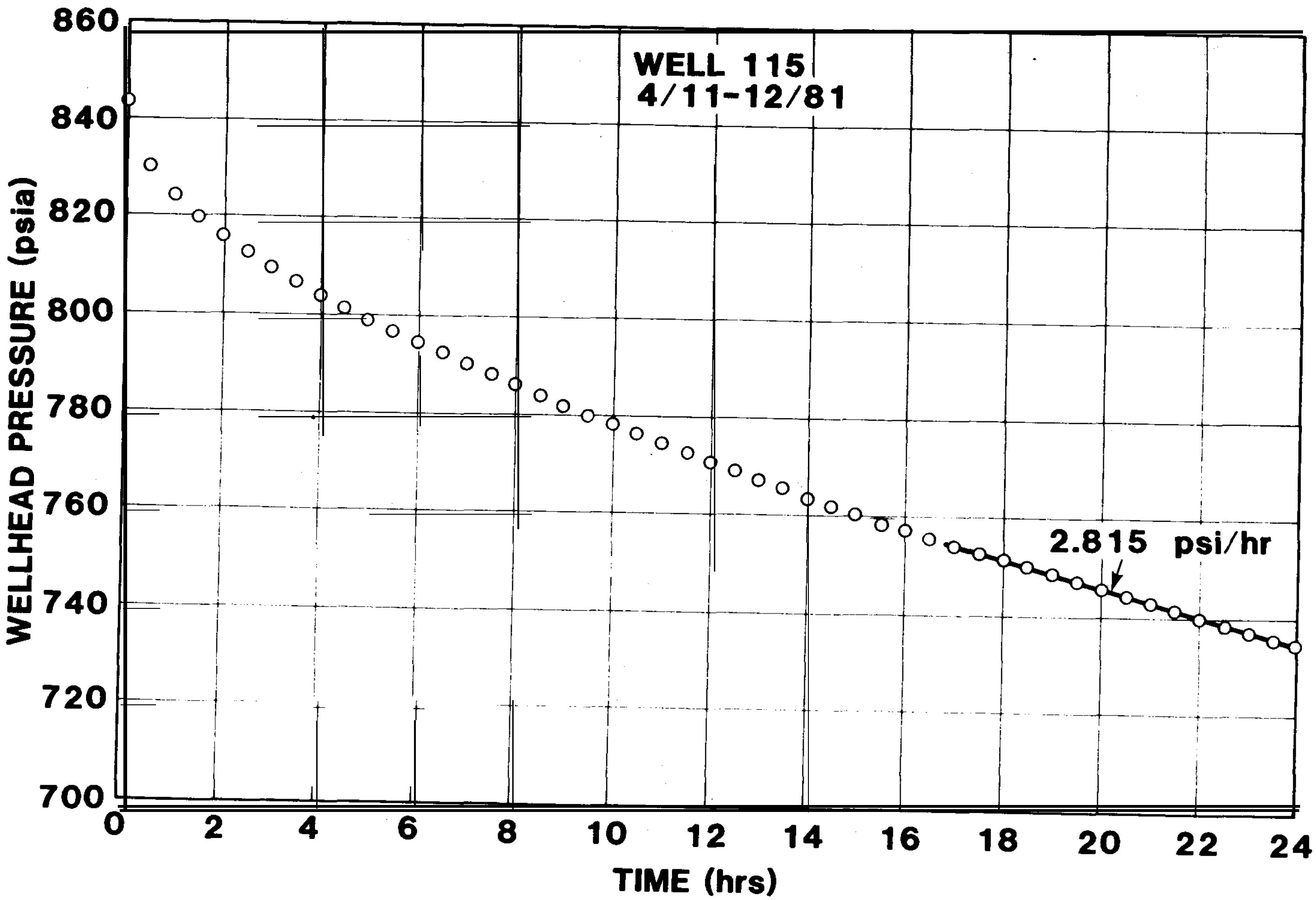


Figure 15a - Pressure-Time History for Well 115



WELL 115
4/11-12/81
2.815 psi/hr
WELLHEAD PRESSURE (psia)
860
840
820
800
780
760
740
720
700
TIME (hrs)
0
2
4
6
8
10
12
14
16
18
20
22
24

Figure 15b

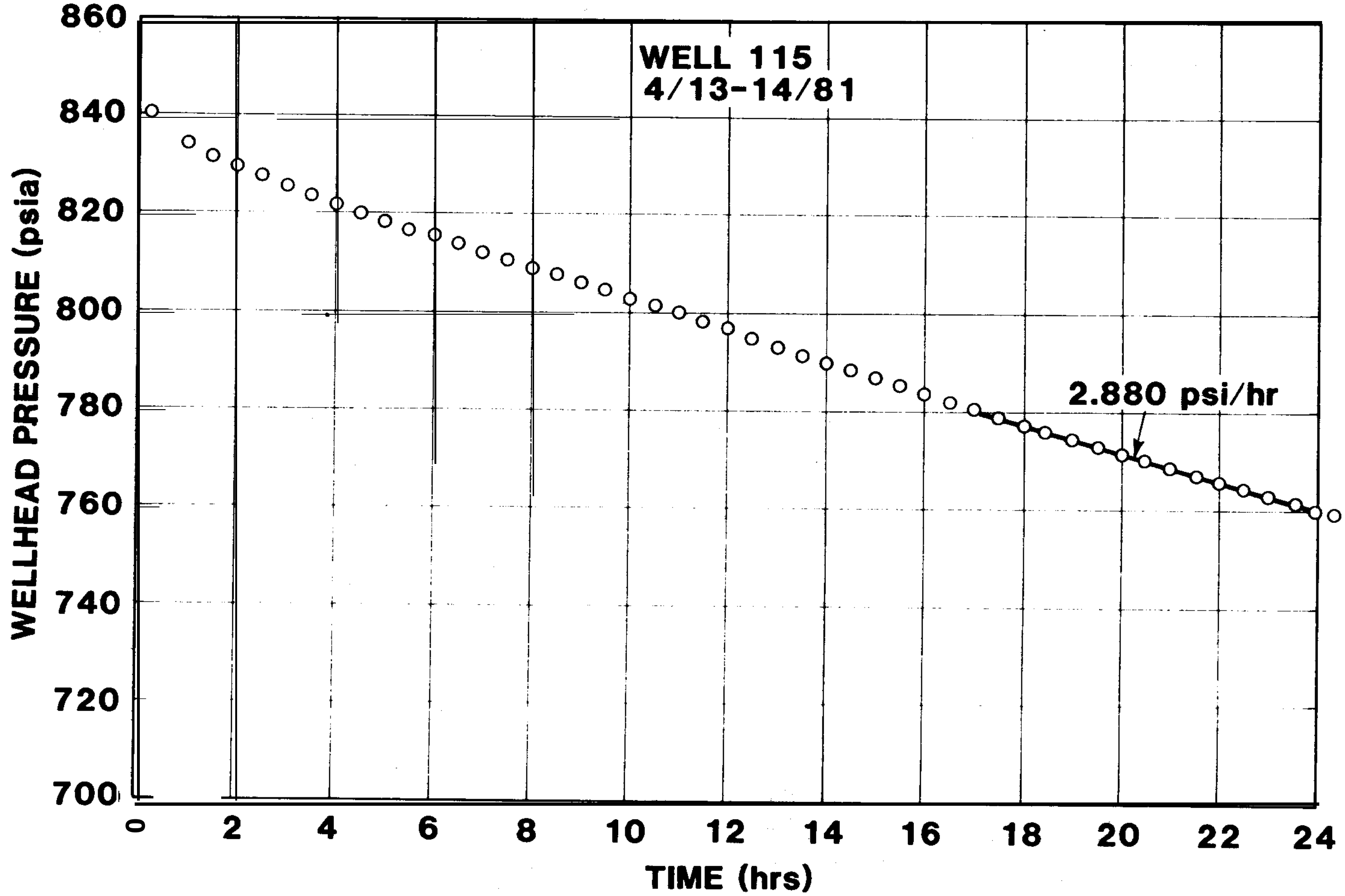

WELL 115
4/13-14/81
2.880 psi/hr
WELLHEAD PRESSURE (psia)
860
840
820
800
780
760
740
720
700
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME (hrs)

Figure 15c

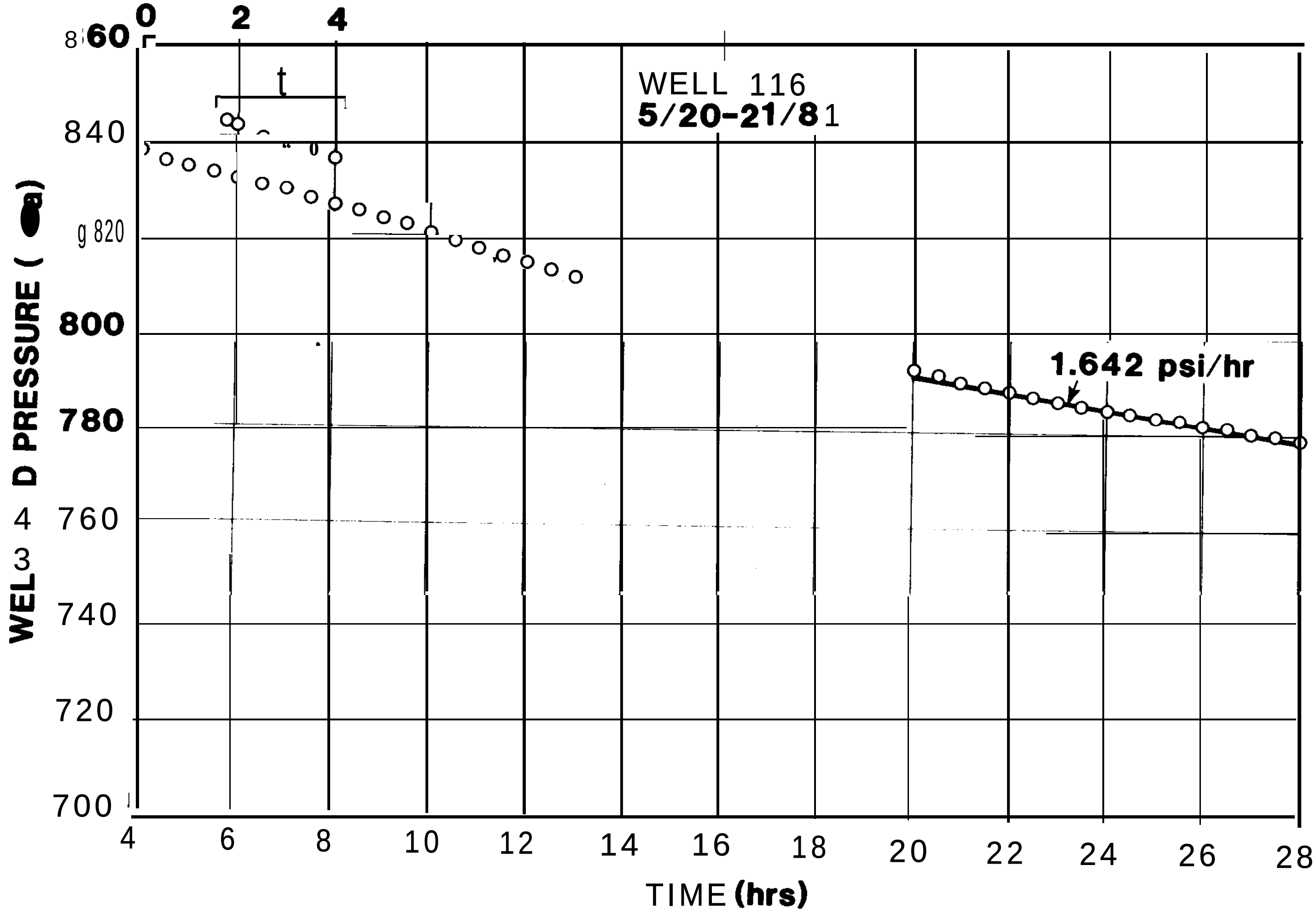


Figure 16 – Pressure-Time History for Well 116

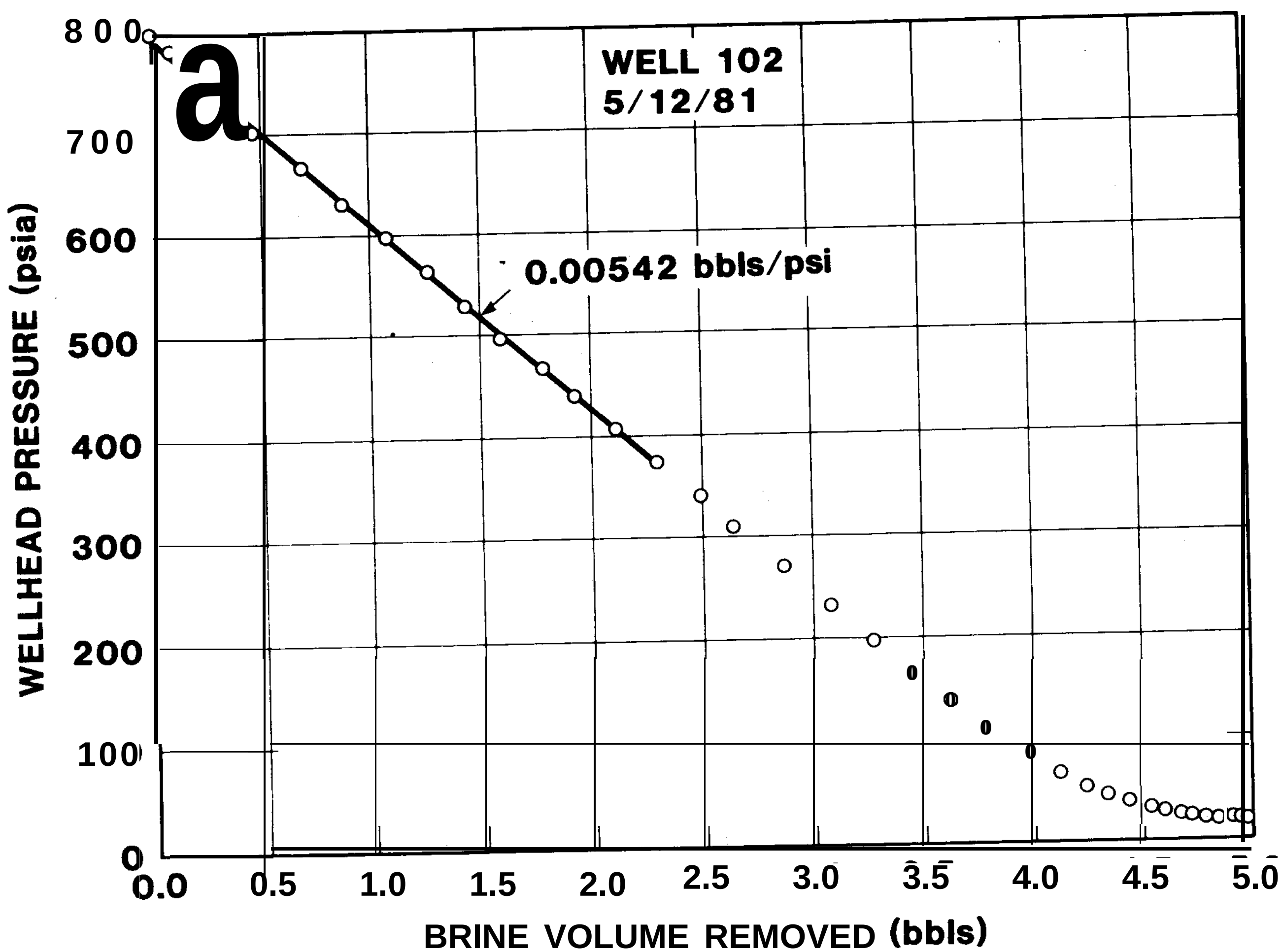


Figure 17 – Pressure-Volume Results During Depressurization of Well 102

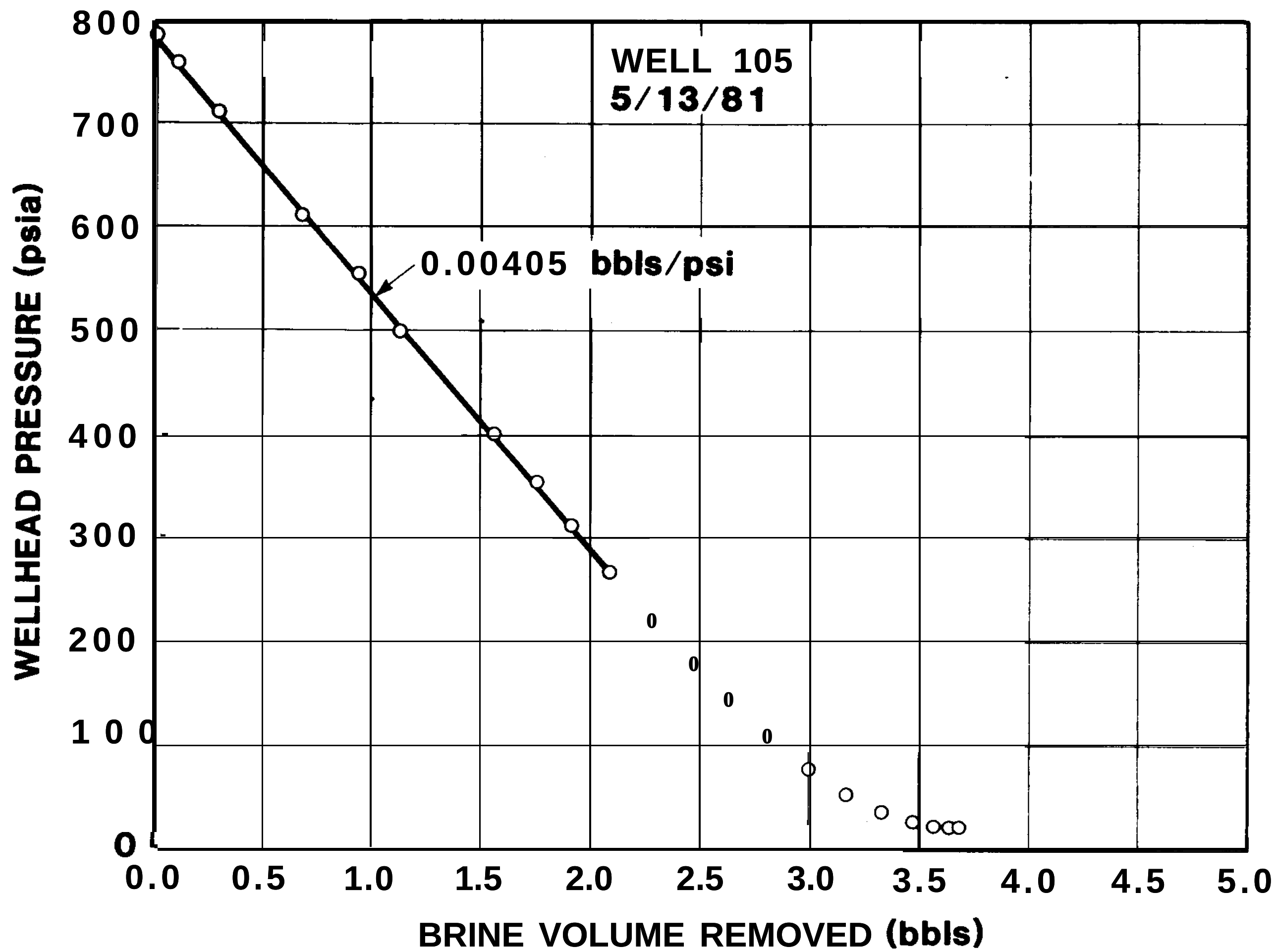


Figure 18 - Pressure-Volume Results During Depressurization of Well 105